# Innovations in science and technology education

## vol. II

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Edited by Dr David Layton

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*Innovations in science and technology education*

Director,
SCERT (WB)

# Innovations in science and technology education

Edited by Professor David Layton

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## Vol. II

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# Preface

*Innovations in Science and Technology Education*, of which this is the second volume, was launched in association with the International Network for Information in Science and Technology Education (INISTE) established by Unesco in 1984. The purpose of these volumes is to provide information, on an international basis, about innovations in science and technology education at all levels of schooling, in related teacher training (both pre-service and in-service) and in out-of-school activities.

The general theme of this volume is science and technology education at a time of rapid scientific and technological change. The publication reviews current trends and issues in science and technology education in the perspective of an educational scene that is changing rapidly. Many of the current changes in education as a whole are due to the impact which science and technology is making on society—though this impact varies greatly from one society to another.

In the face of the need for a general education that will prepare students, both boys and girls, so that they will be 'flexible' and adapt to rapid change and new technologies in the future, what contribution can science and technology education make to this preparation—both for working life and for personal life? This question is examined in some detail in this volume. A further issue is the need for science and technology education to keep pace with new advances in science and technology themselves, in spite of the general inertia of education systems. The publication also reviews the use, in the teaching of science and technology, of educational technologies. It then considers the impact of change on methods for training and re-training science and technology teachers, and on the assessment of students' learning in science.

In addition to an Introduction, there are four main thematic sections:

1. An appropriate introduction to science and technology.
2. Interdisciplinarity in science and technology education.
3. Science and technology education and active life.
4. Materials and methods for science and technology education.

The book is intended for all those concerned with the on-going process of science and technology education. These include science educators in universities and colleges, especially those involved with teacher training and curriculum planning, Ministry of Education officials and practising science and technology teachers.

Appreciation is expressed to the contributors to this volume, who so generously gave of their time and energy. Particular acknowledgement is due to the Editor, Professor David Layton, of the Centre for Studies in Science and Mathematics Education, University of Leeds, United Kingdom.

The editor and the various contributors are responsible for the choice and the presentation of the facts contained in this book and for the opinions expressed therein, which are not necessarily those of Unesco and do not commit the Organization.

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# Part I

# Introduction

# *Integrality and diversity in science and technology education*

David Layton

## Introduction

The eighteen contributions to this second volume on innovations in science and technology education illuminate in different ways and at different levels responses to the challenge of what a nineteenth-century commentator once termed 'bringing science into the hearts and minds of the people'. Since those words were written, the pace of social and technological change has increased in unprecedented fashion, so much so that preparation for a protean future, itself shaped in large measure by scientific and technological developments, now constitutes a major educational goal. Of course, our ability to control that future and to ensure a just distribution of the benefits of science and technology across the countries of the world requires more than improvements in science and technology education. Nevertheless, these have an essential and unique contribution to make.

Reviewing the developments that are described in subsequent chapters, two general tendencies can be observed. The first is towards integrality, in a number of senses. There is the familiar and already well-explored sense of integration of science subjects, as well as of science and technological studies. But beyond, and out of, this there is the attempt to make science and technology more integral with the everyday experiences of learners, with the understandings they have themselves constructed of natural phenomena and with aspects of the life they will experience on leaving school, including embarking on 'work'. This endeavour to restore science to the rich tapestry of 'real life', from which it was historically abstracted as an essential step in its intellectual development, is well exemplified in Lazarov and Golovinsky's account of an experiment in interdisciplinarity being undertaken in Bulgarian secondary schools.

There are other senses in which the innovations move in the direction of integrality, however. Several authors emphasize the notion of both science and technology education as experiences that must each be seen holistically and on a continuum from the earliest years through to adult life. They argue, for example, that technological problem-solving as well as measures to avoid sex stereotyping in relation to science and technology can, and should, commence in primary school, if not earlier in kindergarten and the pre-school years. At the other end of the scale, the idea is extended to the particular and vital problems of teacher education by Power, who argues persuasively for the integrity of pre-service, induction and continuing educational activities, and by Driver, for whom extended involvement in curriculum regeneration is an integral aspect of the professional development of teachers.

There is, then, throughout many of the chapters that follow, evidence of a tendency to redefine boundaries in a way that enables science and technology education to be related to a world of action outside the laboratory and classroom, as well as to the frames of reference, meanings and priorities which learners and their teachers bring with them. Some particular aspects of this tendency to integrality are explored in more detail later in this introductory chapter.

The second general tendency, one towards diversity, might appear on the face of it to pull in the opposite direction to integrality. Rather than a concern for unification and the removal or extension of boundaries, the emphasis here is upon differences and the uniqueness of contexts. In its cultural aspects, diversity relates especially to one of Taylor's key phrases, 'education for individuality'. It is exemplified well in references in several chapters to the localization of curricula and in Tobón's account of how the appropriate national blend of high-, medium- and low-cost laboratory equipment is determined by the economic context, among other factors. Its manifestations are to be found both at the national level, where indigenous curriculum development may yield distinctive versions of science and technology education, and at the regional level, especially in situations where some degree of decentralization has occured. To the extent that what takes place in science and technology lessons is related to the immediate environment, and especially to local industry, there can also be diversity at school level, as Kuitunen and Meisalo describe.

Diversity is not, on closer examination, incompatible with integrality. The broadening of perspectives on science and technology education to bring them back into a relationship with a wider range of human experiences, and to adapt them more effectively to new understandings about learning and new opportunities created by technological advance, does not entail uniformity. It can take place within many diverse contexts. Indeed, in the classroom and the laboratory, the two tendencies converge to support each other mutually, their common goal being more effective learning.

Before turning to examine in more detail some aspects of the two tendencies, a note of caution may not be out of place. Like innovation itself, neither integrality nor diversity is a self-evident 'good' and every change carries with it costs as well as benefits. Diversity, especially, raises difficult questions. As Kelly (1986, p. 63) has noted, the legitimate concern of many countries to mould their curricula to meet the specific economic, social and other developmental needs of their peoples has produced a situation in which 'there is less international accord in science education now than there was in earlier decades'. One consequence, paradoxically, is that we risk 'greater isolation of ideas despite better means of communication'. Unesco's International Network for Information in Science and Technology Education (INISTE), established in 1984, and in association with which the volumes on *Innovations in Science and Technology Education* are published, is an important contribution to the breaching of this isolation, the sharing of ideas and experience, and the fostering of greater international co-operation between science and technology educators. That co-operation would seem essential to the emergence of the counterpoint to diversity—an emphasis on the supra-national dimensions of science and technology education, not least the kinds of problems which transcend national and geographical boundaries and which we face in common, irrespective of location.

## The seamless web of technology

The emergence of technology as a component of general education has been noted in Volume I of *Innovations in Science and Technology Education* (Layton, 1986*b*, pp. 18–21) where reference was also made to Unesco's pilot project on technology in general education in Australia, China, India and the Philippines (pp. 166–7).

(It is clear that many countries have embarked upon efforts to introduce technology into the basic curriculum for all children. In France, for example, under the Law of December 1985, manual and technical subjects in secondary-school education are being replaced by a new programme of technology education which includes informatics, electronics, mechanics and nutrition (Unesco, 1986, p. 48). Technology is very much at the heart of the ten-year programme of technical and vocational education for all 14- to 18-year-olds, commencing in 1987 in the United Kingdom with supporting funds of $1,440 million. Yet despite these and similar developments, a recent global survey of the place of science and technology in school curricula was obliged to conclude that there appeared to be great difficulty in attaching any agreed meaning to the term 'technology' (Unesco, 1986, p. 47).)

In part, the difficulties stem from educational history and the previous establishment in many countries of separate provisions for liberal and technical education, with technology seen traditionally as part of the latter. Its integration into general education entails its transformation from a study with a prime focus on technique and craft skills into one concerned with the fostering of general technological problem-solving capabilities. In part, the inextricable association of technology with values, and with human purposes and needs, engenders a plurality of curriculum manifestations. Attempts to relate education to the world of work and employment, especially in its modern high-technology aspects, have in some contexts led to an emphasis on particular kinds of technology, such as electronics and computer studies. There is perhaps a hint of paradox here, given that high-technology industries often do not require large work-forces.

Another consideration is that the education system into which technology is being implanted can often constrain in significant ways the form that it takes. Existing pressures on the time-table from established subjects, together with the need to work within defined resource limits, led the Indian contributors to the Unesco pilot project on technology in general education to graft technological elements on to existing science curricula, such as science-based technology (Unesco, 1984, p. 13). In Zimbabwe, the decision to revise the secondary-school curriculum to make it more relevant to socio-economic developments was the precursor to a General Certificate of Education (GCE) Ordinary (O)-level science syllabus structured in terms of future employment possibilities and the technological and social environment which the school leaver might encounter, i.e. a technology-based science syllabus (Carelse, 1985; see also pages 101–12 below). Different again, the Australian contribution to the Unesco pilot project began by offering examples of short, independent activities, rather than whole courses, the intention being to indicate ways in which technology education could be incorporated into existing school subjects such as science, home economics, graphic design, metalwork or woodwork (Hawthorn Institute of Education, 1984, pp. 31–7). Typical student projects were: designing swimwear, a child's educational puzzle and a gate-securing device, and propagating plants to restore a bushland area which had been destroyed by fire.

Reviewing these and other developments around the world, it would appear that technology is being integrated into the school curriculum in a variety of ways, which include the following.

### *Technology as a separate subject*

This is often a modular course, components of which may include the study of topics such as structures, mechanisms and electronics, pneumatics is also studied when the high cost of a compressor and air lines is not prohibitive.

### *Technology linked with science (the special relationship)*

Possibilities here include:

Science-based technology courses, in which scientific knowledge and principles are applied in practical contexts, for example, 'household electricity', 'design your diet' and 'combustion for light', three of the topics chosen by the Indian contributors to the Unesco pilot project (Unesco, 1984, p. 13).

Technology-based science courses, in which a technological context of personal and social relevance is used as the basis for the understanding of selected science concepts, as in the new Zimbabwean O-level syllabus.

Science, technology and society courses in which technology as an aspect of culture is the subject of study, especially in its relationship to science and its interactions with society.

### *Technology linked to many subjects (technology across the curriculum)*

First, many school subjects have the potential to contribute to an understanding of technology and to the development of technological capability in students. Thus, few science-linked technology courses, other than science, technology and society courses, appear to provide opportunities for students to explore in depth the value dimensions of technology, the ways in which it has transformed and is transforming society and the possibilities for control of technology. Aspects such as these, unquestionably important, may be more effectively examined in parts of the curriculum other than science, such as history, social studies and possibly religious education. Even so, the drawing together for a student of the multifarious strands that constitute the seamless web of technology—craft skills, scientific knowledge, technological know-how and design, and economic, aesthetic and ethical considerations—requires that there be some focus, which is usually the individual or group project.

There is another sense in which technology can be assimilated across the curriculum into general education. Adoption of the artefacts of technology, most significantly microcomputers and word processors, for the teaching and learning of other subjects can open up exciting new possibilities. As George Marx illustrates on pages 239–54 of the present volume, new objectives become possible in science education by the use of simulations and games. The potential is not restricted to science, however. The practical communicative aspects of learning a language can be enriched when students are empowered to store, edit and transmit text. Technology here can help a school to enter into productive relationships with the outside world. Schools can set up viewdata systems at local centres and, perhaps for a fee, undertake real writing tasks involving letters, leaflets, notices and displays for local industries, commercial houses, hospitals and other municipal agencies (Medway, 1986, p. 8).

Technology can be seen, then, less as a new school subject competing for space in an already overpopulated timetable than as an approach which can infuse many components of the curriculum and aims to empower students to practical capability in real-life situations. It complements academic 'propositional' learning, 'knowing that', with 'knowing how'. In addition to knowledge of concepts, theories and explanatory principles derived from the sciences, technological capability also entails knowledge of artefacts and techniques; for example, how to operate a lathe or use a software package; how to manipulate wood, metal, plastic or ceramic materials; how to project orthographically; and how to handle safely certain animals and plants.

The use of these different knowledge bases to invent a device or to solve a practical problem is not a process which can be reduced to an explicit routine. Its mastery involves tacit understandings, a 'feel' for materials and abilities such as being able to capture and control three-dimensional images in the mind's eye. These may be learnt, but are not readily taught. The customary strategy for their acquisition has been the 'on the job', one-to-one, master-apprentice relationship.

This attempt to restore the integrality of knowledge and action, epitomized in attempts to incorporate technology in general education, poses severe challenges to educators working within traditional institutional structures. Necessary adaptations are hinted at in several of the contributions that follow, as, for example, in Kuitunen and Meisalo's account of activity-based industrial visits in Finland, with their implications for a changed role for teachers, adjustments to the time schedules of students' work, and the reallocation and augmentation of finance. Two aspects merit particular attention, however; the first concerns factors which can help to bring teachers into effective collaboration in multi-disciplinary teaching such as is entailed by technology; the second concerns the assessment of students' technological capabilities.

Much of pedagogical practice in the past, and indeed the architecture of many schools, has been premised on the model of the lone teacher interacting with a class. Furthermore, as both Glasgow and Power note in their contributions on the training of teachers, few science graduates come to teaching with any experience of working as part of an interdisciplinary team. A major prerequisite for collaborative teaching, given the motivation to embark on it, is time for meeting and talking. In a study of teachers' collaborative practices in a sample of Scottish secondary schools, teachers 'stressed the competing demands on their time and the ordering of priorities that had to take place if they were to function at all' (Munn, 1985, p. 43). Blocks of time when all teachers were simultaneously free to meet, plan and develop materials were seen as vitally important.

Sympathetic timetabling alone, however, is insufficient. The geography of a school was also found to be important, collaboration being more difficult if there was no common workbase and if informal contacts could not readily be maintained because of dispersed accommodation. The choice of the co-ordinator of a team of teachers engaged on interdisciplinary work was also a decisive factor, the encouragement of members, sharing the workload, management of resource production and negotiation with authorities all requiring personal qualities of a high order. Perhaps, above all, and given the availability of time and resources, a sense of ownership of the innovation by the teachers emerges as a significant factor, testimony to this again being provided in several of the subsequent chapters.

Turning now to the issue of assessment, the procedures adopted are a powerful determinant of how students approach their learning and of the teaching styles they are likely to encounter. Much of what Giddings and Fraser say in their chapter when commenting on the assessment of practical work in science is relevant to the assessment of technological capabilities, but there are features of the latter which pose special problems.

The most complete demonstration of capability is provided by project work and an immediate incongruity is that, certainly in industry and other real-life contexts, this involves collective and collaborative activity, whereas assessment in schools is almost invariably individualistic. Clearly it is difficult to disentangle the contribution of each student who has played a part in a successful project, but equally it is inappropriate that work in schools should be restricted to individual projects because of the difficulty of assessing group work.

A second point concerns the longitudinal nature of project work, not only in a temporal sense, but also in terms of the complex interactions of activities, ideas and skills needed at particular stages. The generation and defining of ideas for project work is a different undertaking from the design and imaging of solutions, the realization of a chosen design in a constructed artefact and the evaluation of this in terms of explicit criteria. The assessment of project work in connection with external examinations is often conducted on the basis of inspection of the artefact and of a design folder which purports to record the stages of development of the artefact. It is an open question how closely the account in the design folder corresponds to the actual mental and manual processes by which the artefact has been conceived and realized. We lack research into children's technological thinking comparable with that into their scientific thinking. Both teachers and students, however, often acknowledge that the account presented for assessment purposes is a post hoc rationalization in terms of a theoretical model of the technological process, which, as yet, lacks a secure empirical foundation. If indeed we accept that assessment is essentially an exercise in communication (Macintosh and Hale, 1976, p. 30), then, at the very least, a record of extended dialogue between students and teachers, and between students and students, would seem one essential component of the evidence required to assess project work. It is clear that much work remains to be done on the development of more appropriate techniques of assessment if technology in general education is to escape the procrustean proclivities of the examination system.

## Social dimensions of learning

The discussion of group learning interactions in project work provides a reminder that much of students' learning of science and technology does not take place as a solitary activity. For the most part, learners exist in a nexus of relationships, and the social interactions in which they engage and which influence their construction of meanings have a variety of purposes. Another important sense in which innovation in the field of science and technology education is displaying tendencies to integrality is the way in which consideration of these social influences are now being incorporated into our understanding of students' learning. As Joan Solomon (1987) argues in a seminal paper reviewing work in this field, the essential criterion in terms of which 'life world knowledge' (e.g. everyday knowledge of the natural world) is judged is less the internal logic of the explanation than 'that it should be recognized and shared with others'.

Drawing on the work of social psychologists, Solomon has identified 'three separate but overlapping features of social behaviour' which, she claims, might be expected to inform any analysis of social interaction during science education. These are: (a) the *dramaturgical*, meaning the roles we take on for the 'presentation of self' to others and for the public pursuit of our 'moral careers'; (b) *ritual*, which seems to serve a reassuring and enabling function; and (c) *consensus*, which is a need within the social group.

Analyses of transcripts of talk between pupils in small groups doing practical work (Driver, 1983, pp. 104–9; Barnes, 1976, pp. 37–47) and in whole classes learning about energy (Solomon, 1985) have provided illustrations of the ways in which some groups accept the constraints of ritual and manoeuvre for the establishment and preservation of consensus.

These perspectives from social psychology are providing interesting insights into the problems experienced by learners in attempts to integrate scientific ideas into 'the grain of everyday life'. A striking dramaturgical example comes from studies of adults' apparently irrational, or at least non-scientific, behaviour in relation to energy use in the home. In an investigation in the United States, Stern and Aronson (1984) identified five 'roles' which appeared to influence in significant ways the energy behaviour of adults.

1. *The energy user as investor*, who sees the purchase of energy equipment in the home as an investment that will increase the re-sale value. As with the purchase of other commodities, however, additional considerations such as safety, styling and status intrude.
2. *The energy user as consumer*, who regards energy expenditure as providing necessities, comfort and pleasure.
3. *The energy user as a member of a social group*, whose norms influence decisions. A home-owner may know that plastic sheeting over the windows will reduce the heat losses but he or she will not use it because it would 'let the neighbourhood down'.
4. *The energy user as expresser of personal values*. Energy is used in ways consistent with personal ideals or self-image. Thus a spacious, air-conditioned house may be deemed appropriate to the owner's perception of his social position while the installation of solar panels may be reflective of values of environmental concern and self-reliance.

5. *The energy user as problem-avoider*, who is reluctant to disrupt established household routines and accept temporary inconvenience in order to improve energy-use patterns.

Stern and Aronson conclude that the 'energy' of adults in domestic contexts is not the 'energy' of physicists, but a socially defined entity. Furthermore, as we move from domestic to other contexts, such as political arenas where energy policy is debated, it appears that 'there is no single socially shared concept of energy'. It can be viewed with an emphasis on it as a commodity, an ecological resource, a social necessity or a strategic material (Stern and Aronson, 1984, pp. 15–20, 59–65).

How these multiple every-day and context-related constructions of energy can be brought into relationship with scientific constructions is by no means clear. Solomon and others have offered evidence in support of a two-domain theory 'in which socially acquired life-world knowledge is stored in the memory separately from symbolic school knowledge' (Solomon, 1987). Rosalind Driver in her contribution to this volume, after identifying differences between everyday and scientific thinking, outlines an approach for achieving conceptual change which places emphasis on the provision of opportunities for students to make their ideas explicit and to clarify them through exchanges with others, as well as using them in a wide range of situations. The efficacy of such approaches is still to be decided, but what is clear is that the problem of public understanding of science is no longer seen as a scientific or technical problem for individuals, but as a 'people problem' with a strong social dimension to it.

## The challenges of diversity

The implications of adapting science and technology education to take account of the frames of reference and priorities that intending learners bring with them leads naturally into considerations of diversity.

At the national level, indigenous curriculum development has become a distinctive feature of the education programmes of many countries. Jakes Swartland, in his contribution to this volume, provides examples of how the involvement of practising teachers in syllabus reconstruction has led not only to the inclusion of topics judged to be of particular local significance, but also to the emergence of national differences in emphasis on aspects of syllabus content. Similarly, Abraham Blum (page 155) provides an important reminder of the continuing practical importance of an agriculturally based science education for the majority of the world's population and of the need for more effort to be directed to the adaptation of 'existing approaches, techniques and units to different ecological and socio-cultural conditions'. In relation to this, the level of specificity required is well-illustrated by Porfirio Jesuitas' account of an analysis of the community needs of a fishing village in the Philippines and the implications of this for subsequent science and technology curriculum provisions. Some indication of possibilities for redesigning practical work in the teaching of science and technology to make it more supportive of the curricular adaptations taking place is given in the contribution by Adnan Badran.

However, such attempts at indigenization and localization do not exhaust the dimensions of diversity. Recognition of what 'alternative frameworks' or 'naïve theories' individual students bring with them to their science and technology lessons has brought into prominence a view of the curriculum less as a common body of knowledge to be transmitted to everyone than as a set of experiences, designed and negotiated with the teacher, which assist students to develop further their understandings in relation to situations they find problematical (Driver, page 59 below). This perspective, again, carries with it implications for diversity at the level of the individual.

With respect to adult learners, it has already been noted that their interest in science and technology is strongly context-related. As Ziman (1984) has pointed out, there is an important difference in viewpoint between those 'inside' science, with professional involvement, and those 'outside'. For practitioners of science engaged in 'making knowledge', the emphasis is predominantly on the possibilities of discovery and of validation of knowledge claims. In contrast, the outsider's view is overwhelmingly instrumental. Science is of interest to non-scientists largely because of its potential for use. The 'insiders' perspective leads them to 'structure the science curriculum around the central cognitive themes' of their subject, with the result that it is characterized by abstraction and disconnection from everyday contexts (Ziman, 1984, pp. 184–5). Such a generalized version, albeit in theory applicable in a wide range of contexts, is not easily translatable by non-scientists to serve their own specific purposes. It remains a resource whose potential is unrealized or which the public must accept solely on scientists' terms.

Increasingly, however, it is being acknowledged that science and technology have a variety of publics who, in using science and technology at work and in managing their social, recreational and domestic lives, need to make different kinds of demands on science and technology and require different levels of understanding of scientific ideas. Their interaction with science and technology is influenced by priorities and meanings they have constructed from their life experiences; if science is to assist adults to achieve empowerment in relation to real-life tasks and problems, it must be accessible to them in ways that respect these priorities and meanings. In order for science to be returned to ordinary people, to enable them to respond constructively to matters such as radiation risks from nuclear power stations, the prevalence of a disease such as AIDS (acquired immunity deficiency syndrome), the introduction of new technology at the work-place, the use of ionizing radiation for the preservation of foodstuffs or the tragedy of a child suffering from Down's syndrome, it will need to be structured in ways that relate more effectively to the interests of specific groups of adults.

Such 'science for specific social purposes' (Layton et al., 1986; Layton, 1986*a*) needs innovative institutional provisions which for the most part are as yet undeveloped. The Science Shops in the Netherlands (Van der Linde et al., 1982), the Public Service Science Centres established under the Science for Citizens Program in the United States (Hollander, 1984), and the work of bodies such as the Kerala People's Science Movement in India (King, 1986) all offer indications of what alternatives to the traditional 'top-down' mode of bringing science into everyday life might look like. Similarly, recent innovations in the field of interactive science and technology centres, such as those mentioned by Ingrid Granstam in her contribution on the science and technology education of girls (page 47), have the potential to make significant contributions. In all these examples, the emphasis is on science being adapted to people rather than people having to adapt to science. Interestingly, the experience of the Netherlands Science Shops was that, once embarked on this path, gaps in the existing body of scientific knowledge were exposed; science had not previously addressed some of the questions to which customers of the shops sought answers.

Diversity, then, appears likely to be a frequently observed characteristic of science education in the years ahead in both formal and informal contexts and with national, regional and local manifestations. On the one hand, there is good cause to celebrate this rich variety with the prospect it offers of bringing science more intimately into 'the hearts and minds of the people'. On the other hand, it should be recognized that education serves many purposes. The unification of a people by the provision, in formal education and elsewhere, of common experiences which constitute a national culture has been an important educational goal in many systems, and this may be more difficult to achieve in a situation of unbridled curricular diversity. Of course the problem is not new, and the specific tension in relation to science and technology education is merely a contemporary manifestation of one of the oldest curriculum dilemmas: how to reconcile the competing claims of a common and a community-related curriculum. In reality, the situation is more complicated than this, because another function of formal education in most systems is the supply of highly trained scientists and technologists for the maintenance and development of the economy.

Various attempts have been made in the past to resolve the difficulty. Some have entailed a division of the science curriculum in formal education into a common core together with a further component which allows for diversity and local adaptation. Kelly (1986) takes matters a stage further by suggesting a tripartite science curriculum involving 'core, ephemeral and future-orientated' elements, the proportion of each varying as one moves from school through vocational and professional education to adult continuing education. His argument that we need 'to have a clearer understanding of the relation between initial (school) education, vocational and professional education (including universities) and adult

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continuing education', and to plan science education coherently on this wider canvas, is clearly important.

There are, however, other senses in which diversity could be reconciled with unity. In his chapter (page 181) Charles Taylor emphasizes the long-term importance of attitudes, especially in view of the rapid rate of change in scientific and technological knowledge. As several other contributors likewise argue, there is no reason why science and technology should not be part of the experience of even very young children so that enthusiasm for inquiry is fostered from the beginning and science is not relegated to a realm dominated by fear of error and marked by absence of fun. The development of hospitable attitudes towards the natural world which encourage its disciplined investigation in the expectation of achieving understanding and control has not been one of the notable achievements of science education in the past, but that does not invalidate it as a desirable outcome.

In any case, attitudes cannot perhaps usefully be considered independently of process as a unifying factor, though 'process' here is not to be interpreted in any naïve sense of a set of rules for 'doing science' and ensuring 'discovery'. Rather, the view of process that is required is one which follows from the association of scientific investigation with 'craftsman's work' (Ravetz, 1973, pp. 75–108). On this view, though the scientist does have distinctive ways of working, the procedures and judgements involved are learnt mostly by experience and emulation rather than by explicit instruction.

The German chemist Liebig's account of his teaching style illustrates the point well. Writing about his laboratory classes, he stated:

> There was no actual instruction; I received from each individual every morning a report upon what he had done on the previous day, as well as his views on what he was engaged upon. I approved or made my criticisms. . . . In the association and constant intercourse with each other, and by participating in the work of all, everyone learned from the others [Campbell Brown, 1914, p. 40].

In other words, all interactions between teachers and students have judgements and criteria immanent in them and by constant appraisal of students' activities a subtle, tacit, shaping process takes place by which the student is initiated into the traditions of scientific inquiry. No doubt this does embrace activities such as observing, classifying, hypothesizing and the like; but beyond these, there is what Oakeshott (1962, p. 103) termed 'the connoisseurship of knowing how and when to apply them', the craft aspects of scientific activity which distinguishes 'artists' from 'book-keepers' (Holton, 1952, p. 236). The coherence and integrity of these activities enable us to speak of a unique process of science which transcends curriculum diversity. A similar argument might be applied in the case of technology. There is no algorithm for invention, but inculcation into the practice of technological problem-solving is possible because of the integrity of the activities and judgements which constitute the process of technology.

A final, more speculative, solution to the problem of reconciling diversity with unity is opened up by recent work on meta-cognition, in which attempts are being made to 'learn how to learn'. The unifying feature here would be learning strategies that might be acquired in specific contexts and generalized across diverse contexts. Such teaching for transfer entails bringing the transferable strategies into the consciousness of students by adopting teaching styles that encourage reflection about their own learning processes (Nisbet and Shucksmith, 1986; Baird, 1986; Novak and Gowin, 1984). It also requires the application of strategies in a variety of different contexts to confirm their general applicability. Here diversity could be made to work in the service of unity. Perhaps the challenges of diversity are met most effectively by exploiting the opportunities for integrality.

## References

BAIRD, J.R. 1986. Improving Learning through Enhanced Metacognition: A Classroom Study. *European Journal of Science Education*, Vol. 8, No. 3, pp. 263–82.

BARNES, D. 1976. *From Communication to Curriculum*. Harmondsworth, Penguin.

CAMPBELL BROWN, J. 1914. *Essays and Addresses*. London, J. & A. Churchill.

CARELSE, X.F. 1985. Towards a Technology-based Science Syllabus: The New Zimbabwe O-Level Science Syllabus; Country Report. *International Symposium on the Teaching of Technology within the Context of General Education, Paris, 1985*. Paris, Unesco. (Unesco Doc. ED–85/CONF. 809/COL. 12).

DRIVER, R. 1983. *The Pupil as Scientist*? Milton Keynes, Open University Press.

HAWTHORN INSTITUTE OF EDUCATION. 1984. *Technology Education as Part of General Secondary Education. An Australian Contribution to the Unesco Pilot Project on Technology Education*. Melbourne, Hawthorn Institute of Education in collaboration with the Curriculum Programs Section, Education Department of Victoria.

HOLLANDER, R. 1984. Institutionalizing Public Service Science: Its Perils and Promise. In: J.C. Petersen (ed.), *Citizen Participation in Science Policy*, pp. 75–95. Amherst, Mass., University of Massachusetts Press.

HOLTON, G. 1952. *Introduction to Concepts and Theories in Physical Science*. Reading, Mass., Addison-Wesley.

KELLY, P.J. 1986. Future Perspectives for Science Education. *School Science*, Vol. 24, No. 3, pp. 61–9.

KING, K. 1986. Mapping the Environment of Science in India. *Studies in Science Education*, Vol. 13, pp. 53–69.

LAYTON, D. 1986*a*. Empowerment of People: The Educational Challenge of Science for Specific Social Purposes (SSSP). *Bulletin of Science, Technology and Society*, Vol. 6, No. 2/3, pp. 210–18.

——. (ed.) 1986*b*. *Innovations in Science and Technology Education*, Vol. 1. Paris, Unesco.

LAYTON, D.; DAVEY, A.; JENKINS, E. 1986. Science for Specific Social Purposes (SSSP): Perspectives on Adult Scientific Literacy. *Studies in Science Education*, Vol. 13, pp. 27–52.

MACINTOSH, H.G.; Hale, D.E. 1976. *Assessment and the Secondary School Teacher*. London, Routledge & Kegan Paul.

MEDWAY, P. 1986. Leeds University TVEI Curriculum Evaluation Project. Interim Report 9: English. (Unpublished report.)

MUNN, P. 1985. Teacher Collaboration in Multi-disciplinary Courses. In: S. Brown and P. Munn (eds.), *The Changing Face of Education 14–16: Curriculum and Assessment*, pp. 36–45. Windsor, NFER-Nelson.

NISBET, J.; SHUCKSMITH, J. 1986. *Learning Strategies*. London, Routledge & Kegan Paul.

NOVAK, J.D.; Gowin, D.B. 1984. *Learning How to Learn*. New York, Cambridge University Press.

OAKESHOTT, M. 1962. *Rationalism in Politics and Other Essays*. London, Methuen.

RAVETZ, J.R. 1973. *Scientific Knowledge and its Social Problems*. Harmondsworth, Penguin.

SOLOMON, J. 1985. Classroom Discussion: A Method of Research for Teachers. *British Educational Research Journal*, Vol. 11, No. 2, pp. 153–62.

——. 1987. Social Influences on the Construction of Pupils' Understanding of Science. *Studies in Science Education*, Vol. 14. pp. 63–82.

STERN, P.C.; ARONSON, E. (eds.) 1984. *Energy Use. The Human Dimension*. New York, Freeman.

UNESCO. 1984. Consultation Meeting on Pilot Project 'Technology in General Education', Beijing, 1984. *Report*. Paris, Unesco. (Unesco Doc. ED–84/WS/86.)

——. 1986. *The Place of Science and Technology in School Curricula: A Global Survey*. Paris, Unesco, Division of Science Technical and Environmental Education.

VAN DER LINDE, A.; VAN DER LUGT, B.; WEERDENBURG, J. 1982. Science Over the Counter: Politicizing Science? *Risk and Participation. Conference Papers. Second Conference on Science, Society and Education*. Utrecht, Buro Stadium Generale, State University Utrecht.

ZIMAN, J. 1984. *An Introduction to Science Studies: the Philosophical and Social Aspects of Science and Technology*. Cambridge, Cambridge University Press.

# Part II

# An appropriate introduction to science and technology

# Introduction

In a report entitled *Development and Improvement of Secondary Education* prepared for the fortieth session of Unesco's International Conference on Education (Geneva, December 1986) (Unesco, 1986), the scientific and technological challenges to secondary education were analysed under three broad headings: challenges presented by social and cultural needs; challenges presented by manpower needs; girls and women and science and technology.

The first of these related to concerns arising from the unprecedented rate of change in societies brought about by the widespread application of science and technology, themselves self-accelerating areas of knowledge. A principal challenge identified was how to adapt education so that its recipients acquired something of permanent value to themselves and to their societies, despite the fact that the future for which they were being prepared was in large measure unpredictable. General responses in terms of slogans such as 'educating for change' needed to be translated into effective curriculum experiences for children, the provision of which was within the capability of ordinary teachers. As the report indicated, this would entail the introduction into general education of problem-solving and decision-making approaches, and of the inculcation of information locating, retrieving and manipulating skills, often in collaborative enterprises with others. Such prescriptions were unlikely to be effective without the simultaneous development in learners of personal qualities, especially confidence in the ability to cope with new technological situations, and self-reliance and persistence in the pursuit of solutions to problems as these arose. Furthermore, the fundamental goal of all the endeavours provoked by scientific and technological challenges needed to be kept in the forefront of mind by ensuring that 'quality of life' and other value concerns pervaded the curriculum.

Although the report was concerned specifically with the problems of secondary education, the issues identified above are clearly ones whose pertinence extends to education at all levels, from primary to tertiary and into adult continuing education. Indeed, the need to conceive of science and technology education coherently from the earliest years into adult life is a message reiterated by several contributors to this volume.

In the three chapters that immediately follow, the emphasis is on the earlier years, though not exclusively so, and that by George Mills relates particularly to the emergence of technology as a curricular response to challenges presented by social and cultural needs. He stresses the differences between science and technology, recognition of which enables a case to be made for the unique educational outcomes of learning technology, especially in relation to a world of practical action outside the classroom. *Homo sapiens*, man the knower, whose prime goal is scientific understanding, is not identical with *Homo faber*, man the maker, who strives for a general technological problem-solving capability.

Much of Mills' chapter is concerned with ways of encouraging the introduction of technological activities into an already full primary-school curriculum by teachers who lack confidence in their own abilities in this field. The path between a safe, prescriptive and teacher-controlled approach, which stultifies pupil creativity, and a more open and adventurous approach, with the attendant risks of pupil frustrations and disappointments, is a difficult one to tread. Experiences of success in technological problem-solving are as important to pupils as those experiences of success for teachers in achieving worthwhile and practicable technological activities which Mills rightly emphasizes.

There is, for him, no question of technology in primary schools becoming a new school subject. Rather it is an approach which needs to suffuse the whole curriculum and which is fostered through activities in many of the main curriculum areas. Its realization cannot be left to chance, however, and requires a whole school policy, the ingredients of which need to go well beyond an indication of activities and resources appropriate to different stages, to include management responsibilities and provisions for the in-service professional development of teachers involved.

One consequence of the relative novelty of technology as a component of general education in schools is the lack of an established body of research into its teaching and learning. Children's learning of technology has not so far been the subject of sustained inquiry as has children's learning of science. We still lack detailed empirical studies of how children go about technological problem-solving and use scientific and other kinds of knowledge and skills in the design and realization of solutions. In consequence, the development and sequencing of curriculum activities for the fostering of technological capability remains largely pragmatic and intuitive.

The same is no longer true of science education, as Rosalind Driver demonstrates in her review from a constructivist perspective of students' ideas about natural phenomena. Furthermore, she extends her account of the differences found to exist between the thinking of professional scientists and children's ideas on natural phenomena to suggest a theoretically-based approach to curriculum development in science. Even so, as she observes, classrooms are immensely complex places, to an extent that vitiates any *a priori* planning of learning experiences and necessitates development and evaluation of teaching materials becoming itself a research activity. In this process, teachers' practical knowledge of students and classroom life is both drawn upon as a resource and progressively refined in the interaction with information about students' prior ideas and constructivist perspectives on learning. Teacher development so becomes integral with curriculum development.

Returning now to the other challenges to secondary education presented by scientific and technological changes, the second heading was concerned with manpower needs. Detailed consideration of some of the problems of bringing the work of schools into a closer relationship with the world of commerce and industry is given in Part 4, 'Science and Technology Education and Active Life'. The third aspect, however, concerning girls and women and science and technology, is taken up by Ingrid Granstam on pages 47–58.

Drawing especially on the experience of her project on Women and Technology, based at the Institute of Technology, Linköping, Sweden, she describes measures designed to improve the representation of girls and women in science and technology. Like George Mills, she stresses the need to interest girls in science and technology from an early age. Similarly, steps to counteract existing pressures towards sex stereotyping of occupations and life-styles need to be taken from the earliest years. However, it is not just that science and technology are good for girls. Granstam argues, as others have done (Sjoberg, 1986), that girls are good for science and technology. One of her important conclusions is that if more women were professionally engaged in science and technology, their perspectives and priorities would enrich the research effort and contribute to the solution of problems in society in ways unlikely to occur as long as science and technology remain male-dominated preserves.

There are probably no universal solutions to the problem of redressing the under-representation and underachievement of girls and women in science and technology. Support systems which might be effective in one country would be inappropriate in another. The depth to which attitudes about women's traditional roles in society have become entrenched will likewise vary, as will the ability to present successful women scientists and engineers as role models whose achievements might invalidate stereotypes. Much work still remains to be done to emend the general invisibility of women in history and to rediscover and display their contributions to science and technology.

It is also important to recognize that the concept of equal opportunities can in practice be given a number of meanings (Fonda, 1985):

*The unlocked door.* Science and technology courses are open to both boys and girls, but it is left to girls to take advantage of what is being offered. There is no special treatment of either the course or the pupils.

*The open door.* Science and technology courses are again open to both boys and girls, but in this case teachers make a conscious effort to use examples and assignments designed to appeal to both sexes and to ensure that boys and girls have equal access to resources, including apparatus and teachers' time.

*The special escalator.* This stronger version of equal opportunities requires all pupils, both boys and girls, to follow science and technology courses. To opt out obliges them to take a deliberate decision. Boys and girls are expected to acquire knowledge and learn skills relevant to work which is traditionally done by the opposite sex as well as by their own sex. Assignments are designed to reinforce the message that non-traditional options are possible.

*Equal outcomes.* In this strongest version of equal opportunities, all pupils are expected to follow science and technology courses, and support of many kinds is provided in an effort to ensure a similar distribution of boys and girls in terms of attainments and post-school destinations.

It can be a salutary exercise for teachers of science and technology to locate the courses for which they have responsibility on this typology. Recognition of the extent of movement needed in order to achieve equal outcomes is a necessary precursor to the process of innovation and reform.

## References

FONDA, N. 1985. *Four Meanings of Equal Opportunities in TVEI.* Kingston upon Thames, The Prospect Centre. (Unpublished MS.)

SJOBERG, S. 1986. Girls Need Science—Science Needs Girls. In: M.J. Frazer and A. Kornhauser (eds.), *Ethics and Social Responsibility in Science Education*, pp. 231-8. Oxford, Pergamon Press.

UNESCO. 1986. *Development and Improvement of Secondary Education.* Paris, Unesco. (Unesco doc. ED-86/CONF. 207/COL. 6.)

# *An introduction to technology in the early years of schooling*

### George Mills

## Introduction

Over the past decade the word 'technology' has become increasingly a part of everyday vocabulary. In newspapers and the media 'technology' is mentioned or highlighted in the sales description of many consumer products. Modern gadgets and machines invariably incorporate the latest in 'new technology'. In many countries even the youngest pupils are likely to have encountered the word through viewing a children's television programme or in connection with a toy. To adults the impression conveyed is that developments in science and technology are going on constantly, that they are important in shaping our society and that they are complex.

Popular journals and magazines refer to the fear of technology felt by many people. Often this fear manifests itself in anxiety about being able to handle gadgets and equipment and to assemble and operate electrical or mechanical appliances, usually for use in the home. Equipment manuals are poorly understood, misread or misinterpreted. The overall effect is a feeling of frustration and a loss of confidence stemming from an apparent inability to cope with new systems, gadgets or technical data and drawings. The clear inference is that school has not equipped people adequately to come to terms with technology. These, and other factors, have created a demand for a reappraisal of the school curriculum, the aim being that, by the end of compulsory schooling, a person should be technologically literate. As a result, trial programmes in school technology education have been a strong feature of developments in secondary-school education in many countries over the past decade. In the last few years some of these developments have been extended to the primary school, as there was seen to be a need to commence technology education at the earliest stages of schooling.

*George Mills*

# Primary-school science and primary-school technology: the same or different?

The nature of primary-school science education, its curriculum content and activities, strategies for implementation, teaching styles and resource implications have been the subject of numerous publications in recent years (Harlen, 1986).

Recent developments, such as those in Scotland associated with the Primary Science Development Project (MacLeod, 1985), have stressed the need for a policy for primary-school science education which caters for the varying abilities of children at different stages of development. The use of a common-core programme of work for all pupils (aged 8 to 11) which is sequential and progressive over a broad range of science areas, along with extensions to suit pupils of differing abilities, was one of the two recommended approaches suggested by the Primary Science Development Project. This so-called core approach allowed for a compromise between the rigour of a completely structured scheme of work compulsory for all and the freedom offered in the relatively unstructured approach to primary-school science through themes or topics.

There has been no similar detailed attention in documentation and reports to primary-school technology. Indeed, the tendency has often been to use the term 'primary-school science and technology' to replace 'primary-school science', which gives the impression that at this level the terms are synonymous. This is not the case, however. Consideration of some statements as to what is meant by technology readily indicates the existence of a fundamental difference requiring the creation of a whole school policy to cater for the special features associated with technology education. Consider two descriptions of what is meant by technology:

> Technology entails the application of knowledge for making and doing purposeful or useful things. It expresses our ability to employ our resources for human benefit. It is thus to find new and better ways of solving problems and satisfying our needs and comforts [Unesco, 1984, p. 4].

> Technology is concerned with solving problems, meeting needs. In technology, the task, making the artefact or other form of solution, is the end, the resources are the means. The knowledge and skills of science may be some of the resources, but other skills, such as those of design, of craft or of evaluation of solutions, may also be needed [Black, 1984, p. 14].

These statements help to make clear a fundamental difference between science and technology. In its pure form science produces knowledge which gives us insights into the nature of the universe. Science, however, can also be applied to the solving of practical problems and applying science in this manner can be described as technology. The essential difference between science and technology seems to be the matter of intent. Science, whether thought of in terms of method or the products of that method, has understanding as its prime objective. However, when the intention is to use science to produce a technique or product for use by people, the activity is technology.

It is possible to analyse and refine the distinction further, but for the development of technology in primary schools the vital requirement is that the class teacher is aware that technology is different and fully comprehends the nature of the difference. Some appreciation of this can often be acquired when it is pointed out that technological innovations existed long before there was a body of scientific knowledge. One has only to think of the wheel, the bow and arrow, the horseshoe and the bottle, and the impact these had on societies, to be aware that much technology pre-dates scientific knowledge.

When pupils are involved in primary-school science, therefore, they are not necessarily 'doing technology'. Indeed, it is more likely the case that when pupils are involved in technology, and what this entails has yet to be clarified, they will be using science.

## The nature of primary-school technology education

Technology can thus be considered as a productive amalgam of ingenuity, craftmanship and creative engineering that is found where there is a human need to be satisfied or a practical problem to be solved. It follows that any approach to the technological education of the younger pupil must actively foster: (a) the acquisition of strategies for tackling practical problems; (b) ingenuity, novelty and inventiveness in design; (c) practical creative skills; (d) a self-critical approach to the evaluation, testing, development and improvement of a product; and (e) an eye for simplicity and elegance as well as economic utility.

It is by means of practical problem-solving activities that these characteristics will be developed in pupils. In constructing solutions, knowledge and understanding from across the curriculum will be needed, along with a wide variety of process skills, not only from science but also from craft, language, mathematics and elsewhere. It is very likely that the tasks, since they relate to human needs, will involve moral, economic and aesthetic considerations. For many primary-school teachers, problem-solving work will seem difficult, if only because the problem has no right or wrong answer, only good and bad solutions. Technology can be seen to be very much a part of general education and as such it becomes well suited to the ethos of the primary school. This point is reinforced by evidence from the Fulmer Industry/Education Project (Lewin, 1981, p. 2):

> We were delighted to find that primary schools operated in a climate not too dissimilar to that found in an engineering design office... children are encouraged to work on projects related to the world outside the school.

To say, however, that the climate is right is one thing. To go on to suggest that a sound technology programme could be obtained by rearranging or otherwise changing the emphasis on existing programmes would be naïve indeed. A brief look at the history of primary-school science developments is both illuminating and disturbing. Despite major initiatives and projects, sustained success has been difficult to achieve and criticisms are still expressed. One, from the Scottish Education Department (1980, p. 26), states: 'As a matter of priority, something has to be done for them [primary-school teachers] in science.' Another, from the Department of Education and Science (1984, p. 5), is that 'Science suffers... from discontinuity.... A common policy on science education among schools in an area is a rarity.'

Given that, in a world context, primary-school science education still gives cause for concern, one wonders how primary-school technology can succeed, especially in a period of world recession when funds for educational developments are very limited. There can be no easy answer to the question of how to develop primary-school technology education, but if some of the main problems can be identified then solutions may be realized more readily. One thing is certain, namely, that *simple* solutions are needed. Teachers must see that what is required in technology for pupils is manageable and practicable, given a reasonable investment of time and effort on their part.

## Impediments to technology education in the primary school

What approach to technology education will enable the young pupil to develop and mature so that at some later stage of life he or she is able to design, invent, make and operate gadgets or products effectively? What skills are needed for effective learning so that this comes about? How is the wide transfer of knowledge and skills, so obviously needed for this type of competency, to be guaranteed from the different areas of the curriculum which the growing pupil experiences?

These and other questions have to be tackled if a sound approach to technology education is to be established. It is still very early days in this area of primary-school education. In the final analysis, however, a strategy is required which guarantees that every pupil will obtain graded experiences in technology. Ideally, these should take account of the ability of the pupil and span the entire period of compulsory education. Whatever strategy is evolved, experience dictates that any policy for technology education must be undemanding with regard to the main resources of time, teacher competence and finance.

### *Time*

Many educators would agree that their existing primary-school curriculum is already overloaded and regularly faced with demands for additional inputs (e.g. drugs education, computing). To introduce a new main curricular component, and certainly one called 'primary-school technology', would very likely cause considerable debate, if not protest. Such an approach, however, is totally unnecessary since the type of technology envisaged can already be glimpsed in many of the main curricular areas. What is required, however, is that schools be urged to work out a policy for technology within these areas, perhaps initially in the form of a series of technological problem-solving activities for pupils. Eventually these may be used to formulate a planned sequence of work throughout the school similar to the 'core plus extensions' pattern recommended for primary-school science (MacLeod, 1985, Booklet 3). In the first instance, however, the nature of the tasks set and their relationship to the curricular subjects and to each other, will require careful testing and evaluation.

Technology education is thus to be undertaken within the existing curriculum with technology as an integrating factor bringing subjects together. Technology will usually occur in thematic work, in interdisciplinary topic work or in an environmental study; but it may quite readily be incorporated in a traditional subject like mathematics or music or science. This does not mean that technology will be undemanding of time. Quite considerable time must be found within the curriculum for the type of technological problem-solving work envisaged.

### *Teacher competence and confidence*

There can be little doubt that, for many primary-school teachers, the prospect of undertaking work in technology with their pupils will be daunting. Indeed, if this is not the initial reaction, there may be a strong suspicion that the teacher in question views the work as a mere frill. Worse, perhaps it may be viewed simply as something to 'take on board' while continuing to do much the same as before. Part of the difficulty stems from the fact that the meaning of technology and its relevance for the primary school are not fully understood. In these early development stages, this is entirely to be expected and is no fault of the teaching staff. The fact that much technology predates science by many centuries, that it has always existed in the breadth of the curriculum and is there at present, are points which frequently elude even the most discerning teachers. In Scotland some primary-school staff have been found to equate technology in the primary school with work with microcomputers!

Given these misconceptions, the primary-school teacher is unlikely to feel initially either competent or confident to undertake technology work in the form of practical problem-solving tasks. At in-service workshops, however, one positive response that did emerge was that teachers totally agreed that technology's contribution to a pupil's general education could not be ignored. Once the implications of what is involved have been realized, most teachers have appeared willing to incorporate some of the technological activities within their curriculum, if only in an exploratory way. Willingness and appreciation, however, are one thing; competence and confidence are another. Without confidence there can be no successful implementation of a policy. Lack of teacher confidence and a feeling of insecurity among teachers have been major factors in the failure to implement primary-school science successfully. Confidence is best achieved through teachers believing that what they are being asked to do is important and practicable in the classroom, given a reasonable investment of their time and effort. Also, it is essential that they experience success in doing it, as success with pupils is all-important.

To summarize, when introducing technology it is vital that the initial tasks to be tried by the class teacher with pupils are relatively simple, undemanding and lead to success. Only success will allow confidence to grow and enable teachers to move to better things and the school, eventually, to a sound policy. The initial phase of introducing technology should be viewed as *critical*. The danger of expecting too much too soon must be borne in mind by the experts.

### *Financial and physical resources*

Great strides with regard to the provision of appropriate equipment have taken place over the past decade in primary-school science education. Most countries have a large range of printed material available outlining experiments requiring virtually no secondary-school science equipment.

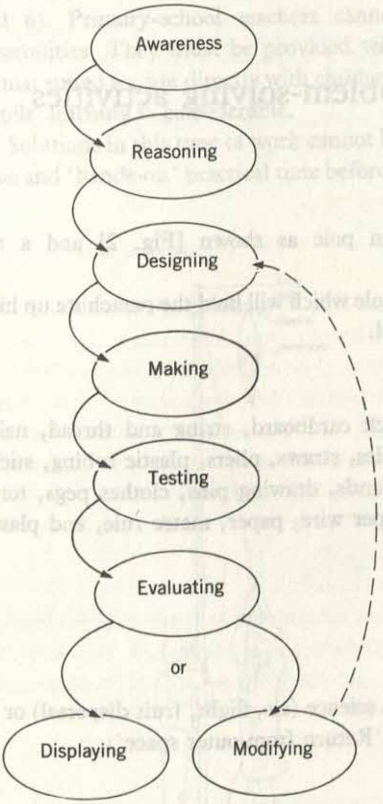
Primary-school science can be taught well using only everyday items and materials. The same solution applies to technology. Commercial kits for construction work can be very useful, enabling exciting projects to be undertaken, but they are not essential. Everyday items and materials can provide the basis for a sound technology programme for the primary school. An important result to come out of trials in Scotland was that cardboard and plastic were preferred to wood in many instances, and that metal was seldom used as it required sophisticated tools. Technology does require that a basic set of simple tools be available (scissors, pliers, hacksaw blades, screwdrivers). Used in conjunction with everyday materials, impressive constructions can be undertaken.

## Technological problem-solving in the primary school

Many areas of the primary-school curriculum provide opportunities for problem-solving activities. Both mathematics and science, for example, can involve children in learning-to-discover solutions. Such activities, however, do not necessarily involve children in the processes inherent in technological activity, at the heart of which is invention. As has been stated, answers to technological problems are neither right nor wrong; rather solutions are good or bad. It is vital to technological problem-solving that pupils become involved and encouraged in thoughtful ingenuity through design, construction and evaluation.

Technological problem-solving is essentially a learning strategy. If it is properly framed, primary-school pupils find it exciting and stimulating. It can be introduced into many areas of the curriculum and, indeed, invariably requires knowledge and skills from a range of subjects.

Technological problem-solving involves pupils in a range of process skills. A simplified sequence of these is shown in Figure 1. Not all technological problem-solving activities entail this precise order of working and involve each of the



Understanding the problem - involves discussion; appreciation of its relevance in the real environment; the constraints posed in the classroom situation (e.g. materials supplied, tools available, time given).

Ideas for solution - drawing on experience; thinking; discussing; researching in books.

Producing a first solution - a drawing or rough sketch; a description; directly using materials to construct a first prototype.

Constructing a first solution.

Trying out the finished product several times.

Does the first prototype meet the needs - what improvements are needed (major or minor or total redesign)?
Factors to be considered, such as aesthetics, robustness, cost.

Finish or going back to the designing stage.

FIG. 1. Sequence of process skills involved in technological problem-solving.

processes. All activities, however, will involve some of the processes and many will involve all of them in the order given. The latter is particularly likely to be the case in primary-school work where special care is required in framing and setting the particular technological task.

Local trials with 9- to 11-year-olds in Scotland revealed that most pupils were satisfied with any solution. Aesthetic considerations were of little concern and a 10 per cent success rate for the product was viewed as quite acceptable and often tremendously satisfying. Motivation was observed to be high and was sustained. Pupils appeared to find the evaluation aspect the most difficult to come to terms with, especially redesigning. It was very rare for a group to change designs and move to an entirely different solution idea. Teachers, however, found they could encourage this step provided they had been supplied with a variety of solution ideas in the form of simple labelled sketches. This emphasizes once again the importance of back-up resources for teachers.

## Framing technological problem-solving activities

### *Exemplar: age 9 to 11*

*Parachute tester*

You are supplied with a long wooden pole as shown [Fig. 2] and a toy parachute.

Make a device to fit to the end of the pole which will hold the parachute up high and allow you to release it when required.

*Materials available*

Scissors, hammer, softwood pieces, thick cardboard, string and thread, nails, putty, paper fasteners, plastic bags, bottles, straws, pliers, plastic tubing, sticky tape, iron wire, gum and glue, elastic bands, drawing pins, clothes pegs, torch battery, bell wire or plastic-covered copper wire, paper, metre rule, and plastic syringes.

### *Analysis of the problem*

### Curriculum placing

This problem could be linked to work in science (air, flight, fruit dispersal) or to thematic work (topics such as 'Airport', 'Return from outer space').

### Relevance

Specific background knowledge is not critical for this problem, (although an electrical solution would require knowledge of the simple circuit), but it would clearly be an advantage if pupils already knew about air, air resistance and how a parachute functioned.

## Technological problem-solving process

The teacher would become involved in discussing the problem leading to the group putting down their ideas in a simple labelled sketch or drawing. Further discussion of the 'plans' would enable the teacher to gauge whether the ideas were feasible. It is sometimes good to allow pupils to embark on totally impractical ideas as lessons can be learned from this.

## Solutions

This problem is capable of many solutions (mechanical, electrical, pneumatic, hydraulic) which is one reason why it was chosen as an exemplar (see Figs. 3, 4, 5 and 6). Primary-school teachers cannot be expected to be aware of these possibilities. They must be provided with the information, accompanied with a format suited for use directly with children. Given this, the possibility for enriching pupils' learning is considerable.

Solutions in this type of work cannot be achieved quickly. Pupils need thinking time and 'hands-on' practical time before a working solution is produced. The aim

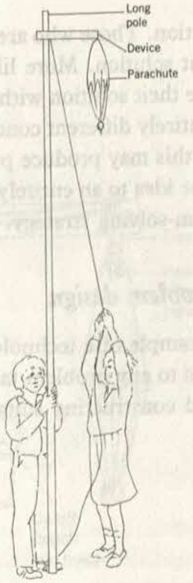


FIG. 2. Parachute tester

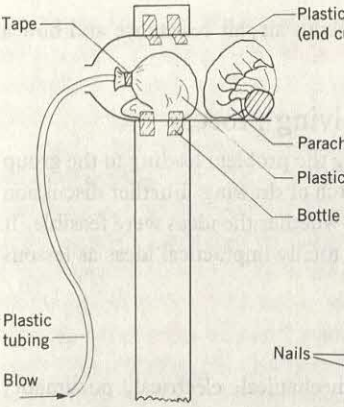


FIG. 3. Mechanical solution.

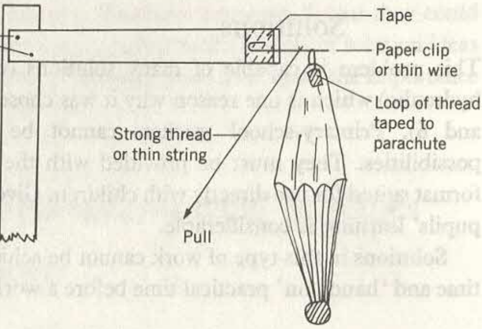

Nails
Tape
Paper clip or thin wire
Loop of thread taped to parachute
Strong thread or thin string
Pull

FIG. 4. Pneumatic solution.

would then be to improve this Mark One solution. Those who are successful in this can be urged to move to an entirely different solution. More likely and feasibly, they could be asked by the teacher to compare their solution with another (selected from Figs. 3, 4, 5 and 6) which involves an entirely different concept. This process enriches the technological menu. Hopefully, this may produce pupils who in later years will be more capable of moving from one idea to an entirely different one, an essential element in any technological problem-solving strategy.

### *Format for technological problem design*

It would be foolish to generalize from one example of a technological problem as there can be effective solutions of many kinds to any problem task. However, the checklist in Table 1 is useful in framing and constructing suitable technological problem activities for primary-school pupils.

TABLE 1. Technological problem design

| | |
|---|---|
| Curriculum area: | |
| Statement of problem: | |
| Constraints (materials, time etc.): | |
| Teaching style (individual/groups/class): | |
| Prior knowledge required: (check past work) | |
| Ideas for solutions (for teacher): | |

## Towards a whole-school policy for technology

In formulating a policy for technology for the whole school, the role of the head teacher and senior staff is crucial. It is their responsibility to have a clear view of the

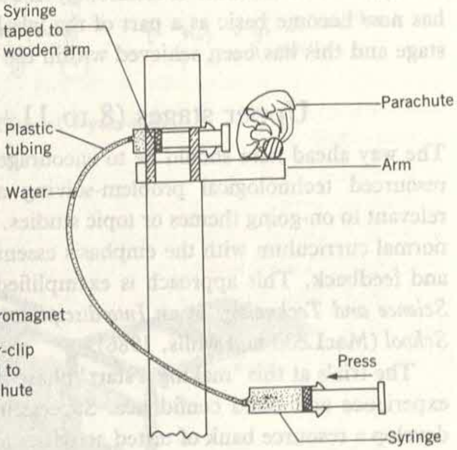


FIG.6. Hydraulic solution.

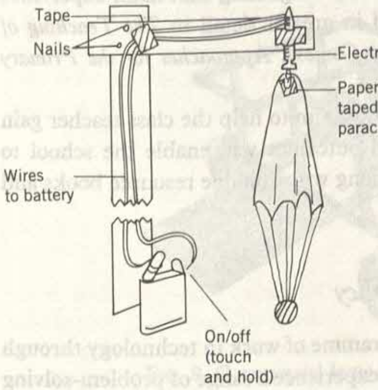


FIG. 5. Electrical solution.

central questions in curriculum planning and to guide staff along a path by which they become able to put into action the programme for technology which finally evolves'. It will require time as well as discussion and in-service provision before such a programme is fully implemented.

At least two phases of development are envisaged.

### *Making a start*

#### Early years (5 to 7)

A great deal of technology is possible even at this early stage through real experiences which involve pupils in an investigative approach to problem-solving and develop both divergent and convergent thinking.

A highly successful pilot study was carried out with 7-year-olds in Scotland (Scottish Science and Technology Forum, 1986) using a large, commercially produced building kit. This gave groups of pupils first-hand experiences of design work in three dimensions, as well as involvement in genuine group decision-making, handling and using equipment, and reasoning and spatial awareness. Always a need had to be met. Pupils became skilled at 'drawing' from three dimensions as well as using their 'ideas sketch' to make a working model (Figs. 7 and 8). Positive attitudes to technology in both sexes were observed. The approach has now become basic as a part of the whole school policy for technology at this stage and this has been achieved within the existing school curriculum.

#### Upper stages (8 to 11+)

The way ahead here should be to encourage staff to try, over a year, a few easily resourced technological problem-solving activities. These should be directly relevant to on-going themes or topic studies. Technology is thus seen as part of the normal curriculum with the emphasis essentially on gaining first-hand experience and feedback. This approach is exemplified in greater detail in *The Teaching of Science and Technology in an Interdisciplinary Context. Approaches for the Primary School* (MacLeod and Mills, 1986).

The trials at this 'making a start' phase must aim to help the class teacher gain experience and build confidence. Successful outcomes will enable the school to develop a resource bank of tested activities along with suitable resource books and materials lists.

### *Framing a whole school policy*

Ultimately the aim must be to achieve a programme of work in technology through the school, which guarantees that pupils will experience a range of problem-solving activities designed to develop the technological process skills and provide a suitable

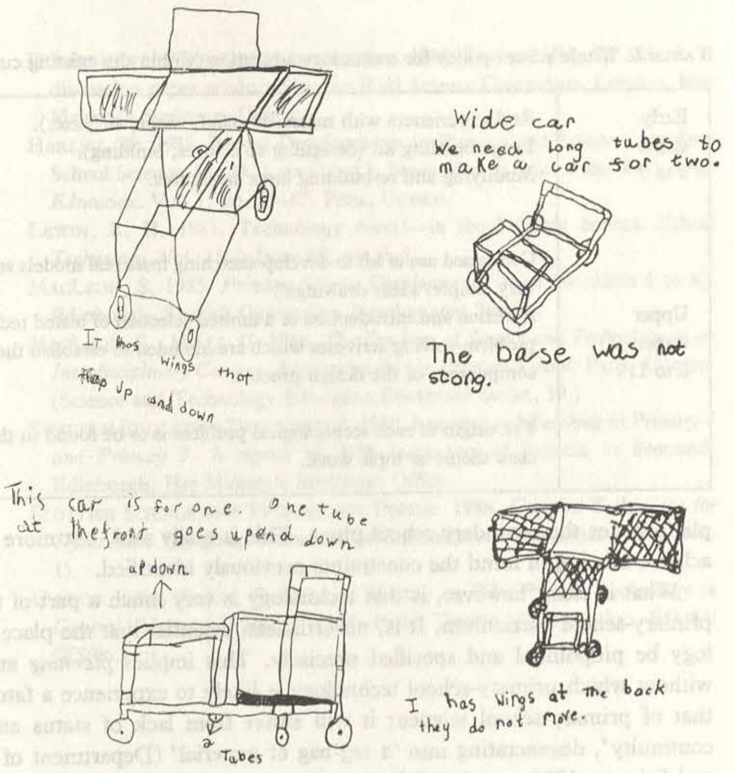

Wide car
We need long tubes to make a car for two.
It has wings that flap up and down
The Dase was not stong.
This car is for one. One tube at the front goes up and down
up down
I has wings at the back they do not move.
a Tubes

FIG. 7. 'Ideas drawings': class of 7-year-olds.

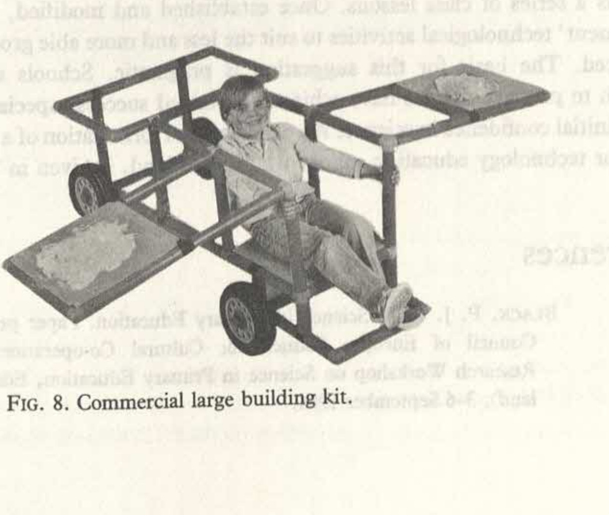


FIG. 8. Commercial large building kit.

TABLE 2. Whole school policy for technology education (within the existing curriculum).

| | |
|---|---|
| Early stages 5 to 7 | Real experiences with materials (sand, water, air., etc.).<br>Large building kit (designing structures, building).<br>Modifying and re-building large structures. |
| Upper stages 8 to 11+ | Continued use of kit to develop sketching from real models and making very simple 'ideas drawings'.<br>Addition and introduction of a limited selection of tested technological problem-solving activities which are intended to establish the principal components of the design process.<br>The origin of each technological problem is to be found in the existing class theme or topic work. |

platform for the secondary-school phase. This is easily said, but more difficult to achieve bearing in mind the constraints previously identified.

What is clear, however, is that technology is very much a part of the general primary-school curriculum. It is, nevertheless, essential that the place of technology be pinpointed and specified precisely. This implies *planning* and *structure* without which primary-school technology is likely to experience a fate similar to that of primary-school science; it will suffer from lack of status and 'lack of continuity', degenerating into 'a rag-bag of material' (Department of Education and Science, 1984, pp. 3 and 5).

A solution being developed in some Scottish primary schools is to adopt a policy for technology along the lines of the 'core approach' to science (MacLeod, 1985). Technology would be compulsory for all pupils but would not be intended to be taught as a series of class lessons. Once established and modified, additional or 'enrichment' technological activities to suit the less and more able groups would be introduced. The basis for this suggestion is pragmatic. Schools adopting this approach to primary science have achieved sustained success especially with staff lacking initial confidence in science. An experimental formulation of a whole school policy for technology education, under trial in Scotland, is given in Table 2.

## References

BLACK, P. J. 1984. Science in Primary Education. Paper presented at the Council of Europe, Council for Cultural Co-operation, Educational Research Workshop on Science in Primary Education, Edinburgh (Scotland), 3–6 September 1984.

DEPARTMENT OF EDUCATION AND SCIENCE. 1984. *Science in Primary Schools*. A discussion paper produced by the HMI Science Committee. London, Her Majesty's Stationery Office.

HARLEN, W. 1986. Recent Developments in Primary and Lower Secondary School Science. In: D. Layton (ed.), *Innovations in Science and Technology Education*. Vol. 1, pp. 29–47. Paris, Unesco.

LEWIN, R. H. 1981. Technology Alert!—in the Primary School. *School Technology*, Vol. 15:2, Issue 60, pp. 2–4.

MACLEOD, S. 1985. *Primary Science Development Project* (Booklets 1 to 8). Edinburgh, Scottish Curriculum Development Service.

MACLEOD, S.; MILLS, G. 1986. *The Teaching of Science and Technology in an Interdisciplinary Context. Approaches for the Primary School*. Paris, Unesco. (Science and Technology Education Document Series, 19.)

SCOTTISH EDUCATION DEPARTMENT. 1980. *Learning and Teaching in Primary 4 and Primary 7*. A report by HM Inspectors of Schools in Scotland. Edinburgh, Her Majesty's Stationery Office.

SCOTTISH SCIENCE AND TECHNOLOGY FORUM. 1986. *Creative Technology for 7-year.olds*. Glasgow, University of Strathclyde. (Occasional Paper, No. 1).

UNESCO. 1984. *Report. Consultation Meeting on Pilot Project 'Technology in General Education', Beijing 1984*. Paris, Unesco. (Unesco doc. ED–84/WS/86.)

# *Girls and women in science and technology education*

Ingrid Granstam

## Why are so few girls studying technology?

There are many indications that the attitude of girls towards technology is established at a very early age. Their notions regarding technology and technical education are formed during pre-school age, in primary and in secondary school. By the age of 10 the difference in attitude of girls and boys to technical and science subjects is already substantial, largely due to differing experiences.

Girls often lack self-confidence and do not believe themselves capable of coping with technical matters even if they enjoy mathematics and physics and would make very good engineers. People around them also take it for granted that boys' interests lie within the technical-scientific area, whereas they asume girls to have no interest in these subjects.

At present, school is obviously not successful in interesting girls in science and technology. It is therefore essential that new teaching methods be worked out for these subjects at all levels of education. In order to increase the interest of girls in technology and to bring about a change in girls' traditional choice of subjects and course programmes certain immediate measures are needed; it is also essential to initiate longer-term changes.

## Why is it so important to get more girls interested in technology?

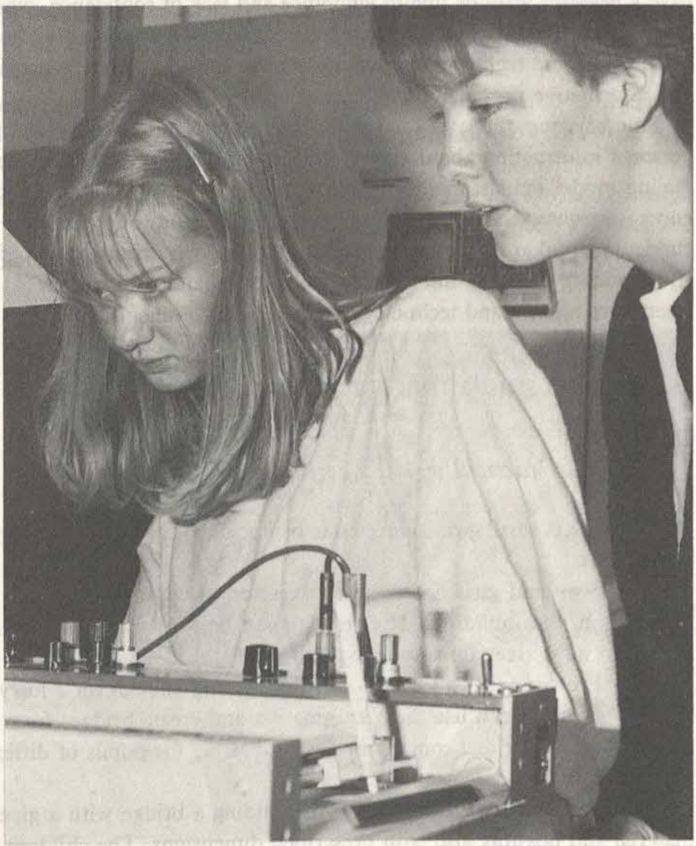
The nature of the labour market is one of many reasons why more girls should be encouraged to study science and technology. Girls usually choose their professions from a much more limited range of occupations than is available to boys. An increasing number of occupations are technical and if more girls studied technology at different levels, fewer girls would be unemployed. The girls would get interesting and developing occupations with an option to work within or outside their own country and on a variety of tasks.

Giving girls an opportunity to do laboratory work.

Society would also profit from more female engineers. Probably they would broaden the scope of technical research, as women often have interests different from those of men. Thus the research effort would be better balanced if both men and women were engineers and scientists.

## How can we get more girls interested in technology?

In different ways we can inform girls about technology courses and the labour market. Very often girls do not believe they can be successful in technical subjects,



Girls find it very interesting doing laboratory experiments at an institute of technology.

as an interest in technology has traditionally been regarded as something specifically masculine. The attitude towards women and technology must be changed, not only in society in general but also among girls themselves. It is therefore important that girls have an opportunity to meet female engineers and scientists, and female technology students, and that girls study technology themselves. Having obtained such information many girls state that technical studies are an option which they are prepared to consider.

We must interest girls in science and technology at a very early age, perhaps as early as 5 years. Subsequently technology must be part of the curriculum all through the years of compulsory schooling. It is necessary to present the subject at the right level so that children will not feel that it is too difficult or too easy for them. In addition, teachers must be trained in technology, since all too often they have a negative attitude due to ignorance and lack of confidence, which they pass on to their pupils. A playful approach to technology is important at the early stages. Mass media and technological activity centres can all be used to provide a positive and informative presentation of science and technology.

Summarizing, then, we can help to interest girls in technology by: (a) improved personal information about career opportunities and available courses; (b) introducing model female engineers as role models; (c) providing technology experiences from a very early age; (d) incorporating the study of technology in the school curriculum; (e) ensuring a supply of appropriately trained teachers of technology; (f) providing positive information from press and radio; and (g) establishing interactive science and technology centres close to schools.

## Recommendations for action

### *Practical technology for small girls*

One way to get small girls interested in technology is through amusing and exciting experiments.

Both boys and girls are usually interested in construction work such as, for example, bridge building. The teacher can construct a model of a landscape, consisting of a river flowing through a small town. Small children can then be motivated to construct a variety of bridges strong enough for a lorry to cross the river. The pupils can use their imagination and create bridges from paper, tape, glue and straw. Bridge construction is interesting for pupils of different age, not only the very young ones.

The older children can compete in building a bridge with a given amount of material and possibly also with prescribed dimensions. The children can compare the bridges and find out which one will show the smallest deflection from a given load and also study which one can carry the heaviest load.

A suspension bridge, large enough for a child to lie on, can be built between two chairs with a board and a rope. The children can also collect pictures of different types of bridges and draw their own.

It can be interesting to talk about spectacular accidents which have happened to bridges due to heavy winds, overloading or some other disaster such as a ship collision. The children can discuss how bridges can be reinforced. Similarly the pupils can make towers.

It is also creative to work with different themes such as a harbour, a town or an amusement park. The children can then build models appropriate to the theme, using a variety of materials including cardboard, wood, modelling clay, flour, pegs or even commercially produced construction kits. Later the models can be brought together to form an exhibition, which can be shown to parents as well as to other classes. The project can be followed up with an excursion so that the children get an opportunity to see an actual harbour, town or amusement park and compare their models with reality.

Boys often show more self-confidence in these activities. It is therefore important to help the girls to overcome their diffidence. They will then cope with the tasks as well as the boys, or even better.

Another example of what can be done with young pupils is the exploration, both theoretically and practically, of the six basic machines: the lever, the inclined plane, the screw, the wedge, the wheel and the pulley. As a rule pupils become

To begin with, the girls in the class may be somewhat hesitant about making models, but they will soon overcome their diffidence and cope with the tasks at least as well as the boys.

more interested in a topic if practical experiments are combined with theoretical explanations. The aim here is to illustrate that a machine is anything that makes work easier, because it helps us, one way or another, to push or pull. Because most of our complicated machines are based on a few simple basic principles which have existed for thousands of years, it is important to make children understand the use of these. One way to get girls interested in technology, which we must not forget, is to explain everyday technical phenomena to them as they are often curious about their surroundings.

## *Special themes and role plays for teachers and pupils*

As early as the nursery school, children can be introduced to various technical occupations. For example, one can discuss the roles which people play in building up a district of a town. Who designs the houses and who decides what buildings are needed? What do the workers do on a building site? What does a bricklayer do? How do the various people interact? What machines and tools are used? Maybe one of the parents has this kind of job and can talk about his or her work. It would be extremely appropriate if one of the mothers had a non-stereotyped technical job! The children can visit a building site, where they can look at various machines and compare different buildings. Back at school, the children can act the parts of different construction workers in role-plays. They can cut pictures out of magazines to make an album of building-site pictures. Finally, they can build a model building site at school. In this case, the children must plan their construction work carefully and share the work between themselves, thereby acquiring practice in team work.

Other special themes might be: technology at home; technology in agriculture; technology in hospitals; technology in transport; technology in communication; or technology and musical instruments.

## *Spare-time activities and theme courses in technology*

Appropriate measures to bring about a more rapid change in girls' interest in technology include arranging seminars in technology for students in teacher-training colleges and offering them practical training in instructive technical experiments. Similar seminar programmes can also be used for retraining serving teachers from different levels of the education system.

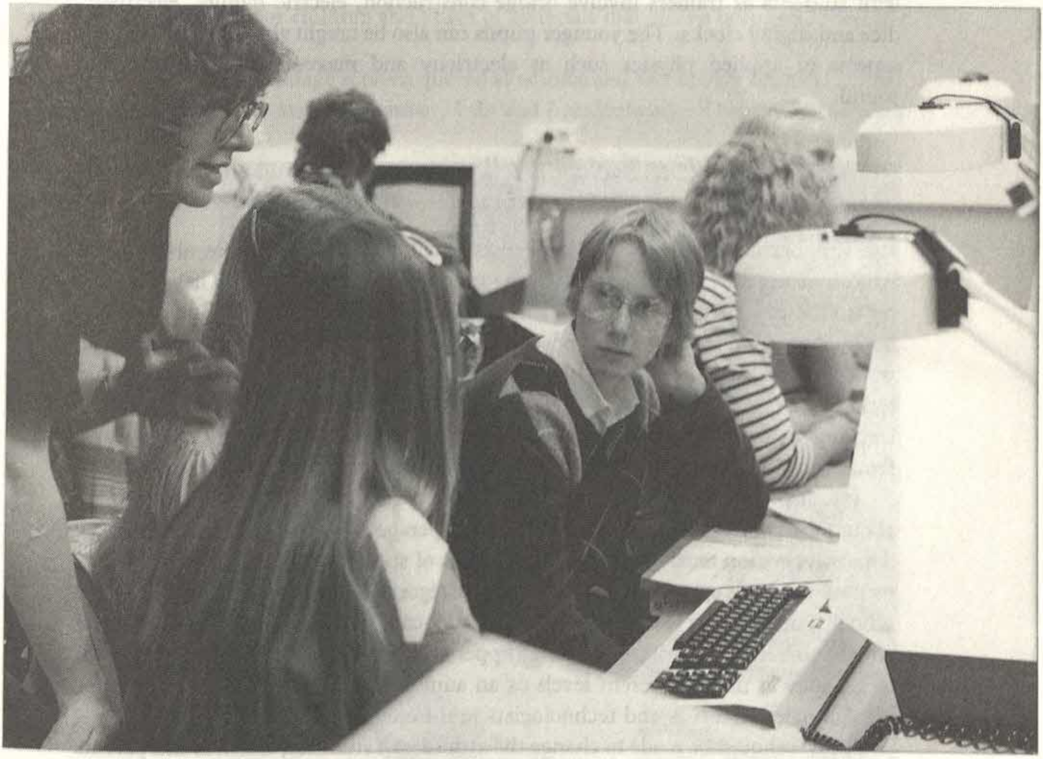
More time needs to be devoted to natural sciences and technology in the training of class and nursery-school teachers. It is also extremely important to emphasize physics, mechanics and mathematics in the curriculum during the years of compulsory schooling.

Teachers must become aware of their importance in the task of changing old attitudes and prejudices. Summer and afternoon courses can be arranged for both girls and boys, and perhaps also for their parents, with engineering students as leaders. In a variety of ways, they can try to bring technology to life for their pupils.

Special computer courses for girls are useful as a means of encouraging more of them to take an interest in computer science. There are still very few female students of computer engineering at university level.

### *Involvement of engineering students in the teaching of technology in schools*

At a university institute of technology, a number of activities can be organized to increase girls' interest in technology. Different projects can be carried out with female technology students acting as trainers in comprehensive schools. The work may be focused primarily on girls, but boys will also be included.



There are very few girls studying computer science and engineering.

The female technology students act both as teachers and as positive models for the young girls. It is beneficial for the children to have young enthusiastic trainers who are interested in science and technology even if they are not familiar with the subjects. It is also beneficial for the ordinary teachers to meet these engineering students. The teachers learn that it is possible to do something positive in technology with pupils, without being an expert in the subject. Science and technology are very far-reaching subjects and one can always begin from a secure, if limited, base, knowing that there are endless possibilities to expand the studies according to the teachers' own interest. In fact, the pupils find it exciting to realize that their teacher also must learn new things; they can work together with new methods, finding solutions to different problems.

If there is no institute of technology near by, then older pupils can be allowed to teach science and technology to younger ones. It is often beneficial for the older pupils as well to have to explain different problems to the younger ones because they must learn the subject well to be able to do it. Experiments which can be done with students as trainers involve bridge construction, electric motors, electronic dice and digital clocks. The younger pupils can also be taught about basic tools and aspects of applied physics such as electricity and magnetism, and light and sound.

### *Female technologists tell young people about their education and occupations*

It is important that female technologists should tell young people about their education and occupations to provide the girls with positive models. They will then regard the prospect of becoming a female engineer as quite natural. One can often hear young pupils say they have never met a female technologist and they therefore wonder what kind of girls are studying technology. Sometimes they think female technologists are outstandingly clever people who have never had any difficulties in learning mathematics and physics. It is therefore beneficial for them to meet young female technologists and see that they are little different from themselves.

It is also useful for the technical students to participate in information meetings about technological education and discuss the perspective of women on technology. This information needs to be focused on girls of specific ages and their parents, as well as careers counsellors and different categories of teachers. Thus, primary-school pupils must be provided with adequate information about technical education before choosing subjects at upper secondary school. One can work with technology at many different levels as an adult and it is therefore imperative for girls to meet scientists and technologists in different types of occupations.

Efforts should be made to change the attitudes of students, teachers and parents towards women's possibilities of gaining a technical education and occupation. Even the role of the mass media is very important and radio and television programmes which depict female technologists at work can help to interest girls in these possibilities. Articles about popular science and technology can also have a positive effect, especially if the author is a female scientist or technologist!

### *Creation of small activity centres in science and technology*

Small interactive science and technology centres can be established in different parts of the country, where people of all ages are welcomed and encouraged to learn by doing. These activity centres are good examples of what can be done to make technology and science interesting for young people as well as for their parents and teachers. Physical phenomena are explained and shown in a pleasant way.

Science and technology centres, if situated close to a school, are very useful to teachers as a way of illustrating science and technology. Many different activities can take place in such a centre, for example lectures about popular science, displays of technological artefacts, training courses for adults, special school programmes, discovery rooms for children and boxes of materials that can be borrowed from the centre.

An old Chinese adage is often quoted at science and technology centres: 'I hear and I forget, I see and I remember, I do and I understand.' This says something

Girls showing an interest in technology.

important about the philosophy from which the idea of science and technology centres has grown.

### *Girls who have made non-traditional choices must be supported*

In the technical upper secondary school it is more common for girls than for boys to abandon their studies. The girls who make the non-traditional choice of technical studies must be supported and encouraged by everyone around them. Their self-confidence will be strengthened if they know that others care about them.

## What is the situation for women technology students?

If you ask female technology students why they began to study at an institute of technology, many of them will say that it was their interest in mathematics and physics that influenced their choice of career. If you ask male technology students the same question they nearly always say that it was because of their interest in technology.

Girls often feel inferior to male technologists in the matter of technical attitudes and the prerequisites for technical studies. It is therefore important to let even young girls become familiar with science and technology. Sometimes you can hear female students talk about how much they enjoyed as children taking part in their father's technical job. It seems as if these early experiences were decisive for their later choice of studies in technology.

Good grades in a range of different science subjects are considered to be very important for successful engineering studies. It is often found that girls' average marks are higher than boys' in mathematics and chemistry, while boys' marks are higher in physics.

When female students decide to study engineering, their parents usually react positively to their choice. Many of the students' friends, however, are not aware of what engineering studies involve and they sometimes feel that the studies are too extensive. If female students are not supported by people around them they run the risk of abandoning their studies before graduation. In many surveys, however, the drop-out at university level is no greater for girls than for boys.

Both male and female engineering students generally enjoy studying at an institute of technology. On the whole, women technology students get on well with one another and with their male fellow students as well as with their teachers. Some students mention that it can even be an advantage to be a women both in working life and at an institute of technology. Women who have graduated are positive in their attitudes to their profession. They are usually well accepted and they are not discriminated against at work because of their sex.

## Conclusion

This chapter has offered suggestions on how to get more girls interested in science and technology. Technology affects us all—women as well as men—and so even very young girls must get practice in technology, so that they will not feel inferior to men in these matters later in life.

It has sometimes been said in the West European press that our age can be characterized as anti-intellectual. This has also affected attitudes to technical subjects. Fear of technological developments sometimes manifests itself in a contempt for technology, and this tends to be more common in women than in men. However, many problems in our society may best be solved by the application of technology that is somewhat different in its social orientation from that which has prevailed in the past.

If more women had a technological education, it is conceivable that this would broaden and enrich technological development and thus benefit society.

## Chronological list of reports and publications from the project on Women and Technology directed by the author at the Linköping Institute of Technology, Sweden.

*Kvinnliga teknologer på maskinteknikliniejn under åren 1970-1980* [Female Engineering Students Studying Mechanical Engineering during the Years 1970-1980]. Linköping, 1981. (LiTH-IKP-S-160.)

*Kvinnor, Teknik och teknisk utbildning, insatser genomförda vid Tekniska högskolan i Linköping läsåret 1978/79 tom 1981/82* [Women, Technology, Technical Education, Achievements Made at Linköping Institute of Technology, from 1978/79 to 1981/82]. Linköping, 1981, 1983 (Second edition).

*Teknikämnet i polsk undervisning, med speciell tonvikt på ansatsen att öka teknikintresset hos kvinnor* [Technology as a Subject in Polish Education, with Special Emphasis on Efforts to Increase Women's Interest in Technology]. Linköping, 1981. (LiTH-IKP-S-158.)

*Rekryteringsfrämjande åtgärder för M-linjen under läsåret 1980/81* [Steps for Recruiting More Mechanical Engineering Students during the 1980/81 Academic Year]. Linköping, 1981. (LiTH-IKP-S-178.)

*Barn och teknik, met speciell tonvikt på ansatsen att öka teknikintresset hos flickor*

[Children and Technology, with Special Emphasis on the Attempts to Increase Girls' Interest in Technology]. Department of Education, Linköping University. (Report No. 1982:79.)

*Polskt skolväsende—speciellt ämnet teknik* [The Polish Education System—in Particular the Subject Technology]. Department of Education, Linköping University. (Report No. 1983:91.)

*Women in Technology*. Department of Education, Linköping University. (Report No. 1983:93.)

*Teknikstationer för barn användbara i lärarutbildningen* [Technical Workshop Stations for Children, Which Can Be Used in Teacher Education]. Department of Education, Linköping University. (Report No. 1983:101.)

*Hur ser 135 teknologer på sin studiesituation. Speciell tonvikt på kvinnliga teknologer på mansdominerande linjer*. [A Survey of 135 Engineering Students at Linköping Institute of Technology, with Special Emphasis on Female Students in Male-dominated Engineering Programs]. Information Office, Linköping University.

*Teknik för barn* [Technology for children]. Department of Education, Linköping University. (Report No. 1984:116.)

*Science Centers i USA och Kanada* [Science Centres in the USA and Canada]. Department of Education, Linköping University. (Report No. 1984:117.)

*Measures to Increase Girls' Interest in Technology*. Linköping, 1985. (LiTH-IKP-S-308.)

# *Restructuring the science curriculum: some implications of studies on learning for curriculum development*

Rosalind Driver

## Introduction

In his Introduction to Volume 4 of *New trends in Physics Teaching*, E. J. Wenham (1984, p. 3) points out the problem of adopting a traditional approach to science teaching: 'To many young minds, this traditional approach is so remote from the world in which they live that they decide that the whole business . . . is quite irrelevant.'

Many arguments have been put forward in recent years for broadening the focus of school science courses in order to make them more relevant to the concerns of the individual and to modern society. Teaching programmes are being developed, for example, which present science principles in contexts which are in themselves seen to be of practical use, (for example, optics in photography, electricity in the home, health science).

It has also been argued that courses could better reflect the scientific endeavour itself, so that students, whether as future citizens or future scientists, may become more aware of both the strengths and limitations of science as a human pursuit.

In this chapter,[1] attention is directed to an additional perspective which also needs to be taken into consideration in our thinking about the curriculum; it is a perspective which draws on our understanding of the learning process itself, in particular how young people learn about the physical world that surrounds them.

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[1] This chapter is based on an invited paper prepared for the International Conference on Trends in Physics Education, Sophia University, Tokyo, Japan, August 1986. The author acknowledges the helpful comments made by Piet Lijnse on a number of points in an earlier draft of this chapter.

## Students' ideas about natural phenomena

There is now an extensive literature, based on studies throughout the world, which indicates that students develop ideas about natural phenomena well before they are taught science in school. In some cases, these ideas (variously referred to as preconceptions, intuitions, alternative frameworks, mini-theories and naïve theories) are in keeping with what is to be taught. In other cases, there are significant differences between the students' notions and the science they will meet in school.

The following examples have been chosen to illustrate some of the kinds of ideas which typically we find in children's reasoning about a range of physical phenomena.

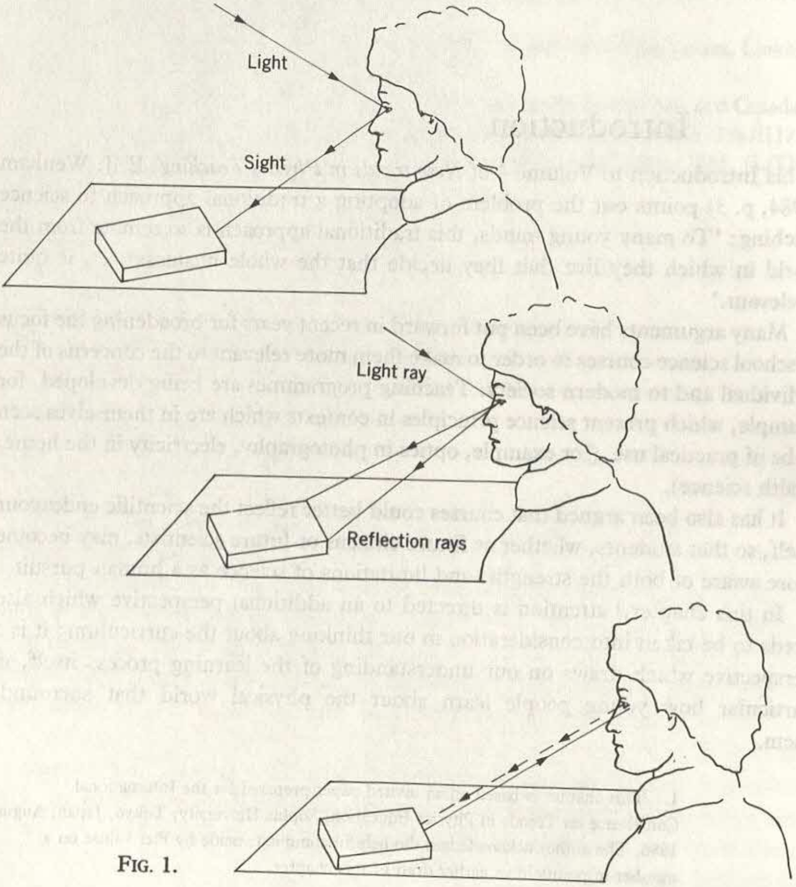

FIG. 1.

1. Children may tell us that the higher up an object is lifted the more it weighs, because when it falls it hits the ground harder.
2. They commonly argue that when an object is pushed, the 'push' goes into the object. This 'push' is lost as the object slows down.
3. Heat is thought of as a kind of 'stuff'. In explaining what happens when one end of a metal bar is heated a 12-year-old said: 'The heat builds up in one part until it can't hold any more; then it moves along the rod.' (Erickson, 1979)
4. 'Hot' and 'cold' may be considered to be distinct entities. In talking about what happens when an ice cube is placed in water a 12-year-old said, 'Some of the cold left the ice cube and went into the water.' (Erickson, 1979)
5. Children's ideas about how they see things may be in terms of 'visual rays' as Figure 1 shows.
6. Energy is a kind of fuel that gets used up. In discussing what happens to a wind-up toy after it is released, a 13-year-old girl acknowledges it has energy when it is moving, but then 'it gets used up' (Brook and Driver, 1986):

> Girl: It's been used up.
> Adult: It can't be destroyed though, can it?
> Girl: No.
> Adult: Where's it gone?
> Girl: He's *used* it. He hasn't *destroyed* it, he's used it.

7. Plants get their food from the soil.

These are just a few illustrations of the kinds of ideas that have been identified in the thinking of young people. Useful collections of papers on studies in this field can be found in Helm and Novak (1983), Jung et al. (1982), Duit et al. (1985), Driver et al. (1985), West and Pines (1985) and Osborne and Freyberg (1985).

## *Students' ideas and classroom learning*

We now recognize that students' prior ideas intrude into all classroom learning situations. In practical activities, students' ideas influence the observations they make, the inferences they draw and even the way they structure an experiment (Driver, 1983). What students understand from more formal learning situations, listening to lectures, reading from texts, is also influenced by the ideas they bring.

Surveys undertaken with large samples of students indicate that alternative ideas in areas such as mechanics or electricity may persist despite teaching, and indeed some may still be used by university physics students (Viennot, 1979; Sjoberg and Lie, 1981).

## *Current perspectives on the learning process*

The research on students' ideas in science and the way they change as a result of teaching can be seen to be part of a broader picture about human learning which is emerging. A key feature in the views of learning, which are current in cognitive psychology, is the idea of mental constructions or 'schemes'. Such 'schemes' are used by learners, whether babies or adults, to interpret new situations. Furthermore, it is also assumed that these 'schemes' are actively constructed by the learner. Learners do not simply absorb what they are told or what they read. From this perspective, learning involves the learner in bringing existing 'schemes' or ways of thinking to bear on a situation in an attempt to understand it. What is learnt thus depends not only on the characteristics of the situation presented (whether it be text in a book or a physical phenomenon), but on the 'schemes' the learner has available. In other words, the learning process is an interaction between the mental 'schemes' of the learner and features in the learning environment. Moreover, since making sense of any new situation requires the learner to bring his or her 'schemes' to bear on the situation and assess their applicability, ultimately the learner is responsible for his or her own learning (Wittrock, 1974).

This constructivist view of learning thus places the learner at the centre of the learning process. What is learnt in any programme of work depends on the prior ideas that students bring, the cognitive strategies they have available and their own particular interests and purposes. Such a view of learning raises fundamental issues for curriculum planning in science. A number of such issues, considered further in this chapter, are as follows.

First, we need to know about the ideas that students bring to lessons, since these will influence the sense they make of learning activities. It is important to appreciate that all parties in a learning environment may be 'seeing things differently'. As a 15-year-old said: 'You know, teachers have got all that knowledge, but we are thinking about it differently because there are so many ways you can take something in' (Osborne and Freyberg, 1985, p. 5). Information about students' prior ideas and ways of thinking can thus sensitize us to their ways of seeing and perhaps provide useful information for the planning of learning activities. Some of the features of students' ideas are outlined in the next section of this chapter.

Second, students' prior ideas, and indeed the reasoning used by most adults (including scientists) in everyday situations, may differ in a number of important respects from scientific thinking. These differences are explored in the third section of this chapter where it is argued that it may be misleading to consider the development of scientific thinking from childhood to, say, university physics as a continuum. Scientific thinking differs from everyday reasoning not just in its content but in its purposes.

Third, learning involves a process of change and development in students' thinking. The way the curriculum is organized needs to take this developmental view into account. This may involve planning for conceptual understanding over periods of years rather than thinking in terms of lessons. Issues in the planning of learning experiences which construct or reconstruct students' ways of thinking are considered in the fourth section of this chapter.

Finally, translating knowledge about the development of students' reasoning into effective learning materials itself requires a research programme. The final section of this chapter argues this point and gives an illustration from a curriculum development programme in action.

## General features of students' ideas

### *Introduction*

As previously indicated, a large body of literature now exists on students' prior ideas about a range of types of phenomena relevant to various branches of science. Investigations have been undertaken in the areas of dynamics, light, electricity, heat and temperature, air and air pressure, plant nutrition, classification of living things and the nature of matter, as well as into students' cosmological ideas.

Clearly it would be impossible to summarize these studies in a way that does them justice. Instead, some general features of students' ideas which can be identified will be discussed. This focus on the ideas of students, the group of interest to us during schooling, is not intended to indicate that adults too, even scientists, do not think in similar ways when considering everyday problems. This point is developed below.

### *Students' ideas as active schemes*

Although there is evidence from studies of learning during school years that students' ideas may not be easily changed by instruction (Tiberghien, 1986), it would be giving a false impression of children's reasoning to suggest that such ideas are in some way a fixed or static set of notions. They might be better portrayed as an array of possible 'ways-of-seeing' which are available to students and can be tried in novel situations. As Claxton (1986) suggests, they are tools for learning and form a basis for new understanding through a form of analogical reasoning. Early experiences of young children pushing objects on the floor—an action producing motion—are used as a basic scheme to which other types of pushing motions are assimilated; play with water may provide a basic scheme for later developments of the notion of flow.

Children try to understand novel situations by visualizing them as something they know or recognize. Exploring an unfamiliar balance beam, a child may soon

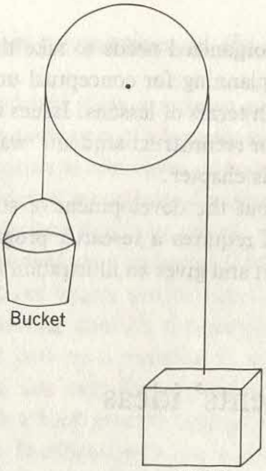

FIG. 2. Bucket and block of equal masses suspended from a pulley at different heights.

say, 'It's like scales.' The new situation has been assimilated into the child's notion of scales, where the behaviour of the scales is taken for granted rather than something to be explained.

This dynamic picture of children's reasoning is clearly in evidence when novel situations are assimilated into inappropriate schemes. For example, even undergraduate physics students, when faced with two equal masses held at different heights over a pulley (Fig. 2), will predict that the two masses will move until they are level (Gunstone and White, 1981) using arguments like, 'They level up like a balance.' Children are often surprised that the pressure in a liquid acts in all directions. They tend to use their scheme for the weight of a solid body, a force which acts in a downward direction only, to interpret what is happening in a liquid (Engel Clough and Driver, 1985*b*).

### *Students' ideas are coherent within a way of thinking*

An important feature in understanding children's thinking is to appreciate that the conceptions they use may be coherent when viewed from the child's perspective. In the area of dynamics, for example, we know that students commonly associate a constant force with constant motion, a notion which is well adapted to a world with friction. What they mean by 'force', however, is not the same as what a physicist means. In cases like this, we see that a student's conceptions make sense within the student's own way of seeing things. In this sense, they are not wrong, just construed differently. In understanding students' thinking, it is important to ask ourselves in what way this idea makes sense. In a recent study of children's notions concerning the dissolving process, some younger children said that sugar when stirred in water turned to water. Further probing indicated that for them 'water' meant any clear liquid. On these terms, their answer—that the sugar was still there though it had changed to water—made sense.

### *Context specific reasoning*

It is a characteristic feature of children's ideas that they are limited in their generality and tend to be related to specific contexts. Situations which may be 'seen' to be similar from a scientific point of view may be interpreted using different notions by children. The majority of a group of secondary-school students, for example, explained what they felt when touching a hot spoon in terms of heat or heat energy coming to their hand. However, when presented with a cold metal object, only a minority explained this in terms of heat or heat energy leaving their hand. Instead, many of the answers ascribed the property of coldness to the object (Engel Clough and Driver, 1985*a*). These two ways of interpreting were not seen as inconsistent by the students concerned. Indeed, in some cases where inconsistency is noticed, it may not be seen as an issue. This points to a very significant difference between everyday thinking and scientific thinking where coherence and parsimony are important criteria. In everyday thinking, what is important is that our ideas about a situation 'fit' that situation, enabling us, if necessary, to predict and act within it. The ideas can be context bound and of limited generality and still enable us to do this. Everyday thinking may thus consist of a collection of situationally specific ideas whose relation to one another is not of prime importance.

A further feature which we notice about children's ideas is that an individual may respond to the same situation using different ideas on different occasions. This indicates that individuals have a range of 'ways of seeing' a situation available to them. It is probably this pluralism that enables learning and conceptual change to take place at all.

### *Differentiation of ideas*

The ideas that children use may reflect relatively undifferentiated notions. For example, children's ideas concerning weight often incorporate aspects of volume, solidity and pressure. 'Air' for children may have connotations of a general medium for the transmission of effects; for example, children often associate air pressure with gravity. Electricity is a general undifferentiated notion incorporating power, current and energy. This undifferentiated character of some notions enables children to slip from one meaning or aspect to another without necessarily being aware of it (a factor that goes some way to interpreting the inconsistencies in their thinking).

### *From perceptual to conceptual thinking*

There are a number of ways in which children's ideas develop as they get older. In younger children in particular we note that their notions tend to be perceptually dominated; when a substance burns, matter disappears; when we drink through a straw the liquid comes up because of the 'suction' in our mouth. In neither of these cases do children posit the existence of entities such as air, or gases, which they cannot see or feel. However, as children grow older they incorporate more ideas which refer to entities not directly perceived.

### *Focus on properties rather than interactions*

Younger children's thinking is also characterized by a tendency to give interpretations in terms of properties of objects rather than in terms of interactions between systems. For example, the differences in sensation between touching metal and touching plastic are explained in terms of metal being an intrinsically cold substance and plastic a warm one. Weight, an extremely complex notion for youngsters, is seen as a property of a body rather than as an interaction between an object and the earth.

### *Causal reasoning*

Studies in a number of areas point to the fact that children's reasoning focuses on changing states rather than equilibrium states. We note, for example, that children acknowledge that a force is acting when motion is observed, but forces are less likely to be considered in systems in static equilibrium (this being seen as the 'natural state' of the system).

The idea that it is change that requires explanation is at the root of children's causal reasoning. In giving explanations, children's reasoning tends to follow a linear causal sequence. They postulate a cause which produces a chain of effects in a linear order in time. This form of reasoning has been identified in children's ideas about a range of phenomena and it has been suggested that it has its origins in early action schemes of young children (Andersson, 1986). A feature of this form of reasoning is the tendency to think in preferred directions rather than appreciating the symmetry in interactions between systems. For example, in considering a kettle of water on a burner, children tend to think in directional terms with the burner as a source, supplying heat to a receptor.

A consequence of this directional way of thinking is that processes which a scientist considers in a reversible way are not necessarily seen this way by children. For example, they understand that an input of energy may change the state of a substance from a solid to a liquid (energy 'breaks the bonds') yet have difficulty in understanding the reverse process when a liquid solidifies. (They interpret the energy as an 'action on the system' to break the bonds and are left with the problem of where the bonds come back from!)

This way of thinking about explanations differs in a fundamental way from explanation in scientific thinking.

## Scientific thinking and everyday thinking

### *Introduction*

The previous section outlined some of the characteristics of children's ideas and it was suggested that adults' everyday thinking may share similar characteristics. In what ways does everyday thinking differ from scientific thinking? In this section differences of three types are examined: first, in the content and scope of the ideas; second, in the way ideas are structured and related; and third, in terms of their assumed purposes. These will be discussed in turn and the implications of taking each into account in curriculum planning will be considered.

### *Differences in content and scope in ideas*

There is clear evidence that the ideas that children use to interpret phenomena may differ significantly from those they are taught and that these differences may involve quite fundamental assumptions about the way things happen. Such differences in ways of seeing things can act as 'critical barriers' (Hawkins, 1978) to understanding in a number of domains.

We have seen that students tend to think that an 'action' is necessary to keep something moving. This notion influences their understanding of classical mechanics, but also intrudes into other areas. For example, when the kinetic theory of gases is first introduced at school, the idea of intrinsic motion of the particles is a basic conceptual problem for many students: 'What keeps the particles moving?' and 'What makes them move in the first place?' are questions that often arise in discussion (Nussbaum and Novick, 1982; Wightman et al., 1986). Children's notions about air, substance and weight have an influence on what they understand about a range of scientific topics (including notions of combustion, as well as matter cycles in living systems).

It is conceivable that these changes in thinking do not take place over short periods of time. Indeed, the necessary restructuring of ideas may require a period of years rather than one or two lessons, and this may necessitate taking a developmental view in any long-term curriculum planning. As Strauss and Stavy (1982, p. 592) suggest:

> a curriculum unit which encourages children's activities and verification experiences, if not based on a thorough understanding of the development of children's competences about the concept, is essentially blind and should not be expected to be successful as a teaching instrument . . . we need to know the developmental picture before decisions can be made about curricular content, its sequencing and timing.

A useful example of our need to understand the developmental sequence in children's thinking can also be taken from Strauss's work. He has explored areas of children's experience where their performance actually appears to decline before improving (exhibiting U-shaped development). One of these areas which has been thoroughly researched is the development of children's understanding of temperature as an intensive quantity (Strauss and Stavy, 1982).

In one of the research tasks, children between the ages of 4 and 13 were presented with two cups of cold water and a third empty cup. They were asked: 'The water in these two cups is cold. Now watch. I'm going to pour them into this cup here. What do you think the water is now? Why?' The percentage of the children giving the correct judgement—that the temperature of the mixture would be the same—is shown in Table 1.

Strauss identifies three developmental periods in terms of the justifications given by children. In the first period, the youngest children give explanations based on identity, 'It is the same water you had before' or 'You only poured it'. The

TABLE I. Children giving correct judgement for temperature task (percentages)

| Age | Children giving correct judgement |
|---|---|
| 4 | 65 |
| 5 | 35 |
| 6 | 15 |
| 7 | 50 |
| 8 | 30 |
| 9 | 55 |
| 10 | 55 |
| 11 | 85 |
| 12 | 85 |
| 13 | 80 |

*Source*: Strauss and Stavy, 1982.

second period is characterized by references to the amount of water in the cup. Children say that the cup with more water is colder. In the third period, children return to the identity reasoning, but often explicitly exclude volume as a factor. 'The amount doesn't matter', 'Water at the same temperature doesn't change its temperature all of a sudden if you mix it.'

This is a particularly useful example to consider since it indicates that while sophistication of reasoning may increase in terms of the factors taken into account, children's actual performances may not improve.

An appreciation of the ways in which children's ideas are related may also be required in planning a developmental curriculum. A number of studies have been undertaken at Leeds, United Kingdom, into schoolchildren's ideas about air and air pressure, (Engel Clough and Driver, 1985*b*; Miller et al., 1985). One of the tasks used with 11-, 13- and 15-year-olds asks students to explain what happens when a liquid enters a syringe. The types of responses given for different age groups are shown in Table 2.

We notice a small but positive increase in the proportion of children referring to the action of the air on the outside of the syringe. Although nearly all acknowledge the existence of air, the majority focus only on what is happening inside the syringe, explaining the action either in terms of the vacuum or suction as an agent or the air/air pressure inside pulling the liquid up.

TABLE 2. Secondary-school students' responses to the syringe task (percentages)

| Response | Students | | |
|---|---|---|---|
| | Age 11<br>N = 46 | Age 13<br>N = 65 | Age 15<br>N = 86 |
| *Explanation involving air pressure outside* | 2 | 12 | 14 |
| Air pressure outside greater than inside | (0) | (0) | (9) |
| Air pressure outside makes water enter syringe | (2) | (12) | (5) |
| *Explanation involving action of air inside syringe* | 32 | 28 | 30 |
| Pressure lowered inside | (4) | (5) | (15) |
| Air/air pressure/pressure in syringe pulls water up | (28) | (23) | (15) |
| Vacuum/suction explanation (no mention of air) | 24 | 40 | 26 |
| Tautology, description (pull the plunger and it goes up) | 11 | 5 | 6 |
| Other | 30 | 15 | 19 |
| No response | 0 | 0 | 6 |

This raises the question as to how children understand the action of the air. Here an investigation into children's ideas concerning air and weight possibly offers us some insights. Children were shown a balance beam in equilibrium with plastic containers at each end. The container at one end was removed and additional air was pumped into it. Children were asked to predict what they thought would happen when the container was returned to the beam. Responses in terms of 'air is light and rises' or 'air is weightless' were quite common as the results in Table 3 show.

TABLE 3. Secondary-school students' responses to the weighing-air task (percentages)

| Response | Students<br>Age 11<br>N = 29 | <br>Age 13<br>N = 54 | <br>Age 15<br>N = 61 |
|---|---|---|---|
| Air is light, makes things lighter or air rises | 38 | 20 | 11 |
| Air is weightless | 17 | 15 | 8 |
| Air has weight, makes things heavier | 28 | 59 | 53 |
| Other | 7 | 2 | 15 |
| No response | 10 | 4 | 13 |

The complexities that children are trying to come to terms with are illustrated in the following discussion between 13-year-olds about a version of the task using balloons on a balance beam:

Daniel: Air's heavy, right? It's heavier, isn't it?
Joanne: No.
Daniel: It is, it is!
Ann: It's the same, air weighs nothing.
Daniel: Look, it'll go down—air's heavy.
Jaspal: Look, listen! When we blow the balloon up it's going to come down, isn't it? Because the air in the balloon's heavier and gravity pulls it down.
Joanne: Yes, but air's light, so how can it come down?
Ann: It floats so it'll stay the same.

*After they have tried it out:*

Ann: Hey, it's gone down!
Joanne: But what makes it go down?
Jaspal: Look, we're learning about air, right? It's heavier than normal air outside—gravity pulls the balloon down.
Ann: Air's light, it'll make the balloon float.
Daniel: How come it came down then?
Ann: I don't know. I thought it'd stay the same.

Joanne: If it were light it would go up, wouldn't it?
Jaspal: Look, gravity pulls it down—it pulls the air down.
Daniel: Only when it's in the balloon.

There are many aspects of interest in this interchange, including the observation that the empirical evidence itself does not explain the phenomenon. Some of the children clearly think of air as 'floating about' and hence weightless. This has the consequence that they ignore the effect of air on surfaces unless there is mass movement of the air (Séré, 1982); 'pushing' on something comes either from 'motion', or because of 'weight'. If, as far as children are concerned, still atmospheric air has neither of these properties, how can it exert a pressure? If the notion of atmospheric pressure is to be constructed in a meaningful way by children, then they have to resolve these issues.

The paths that children tend to take in their scientific understanding have been explored recently in a number of areas including light (Guesne, 1984; Andersson and Kärrquist, 1983), heat and temperature (Strauss, 1982; Erickson and Tiberghien, 1985), and simple electrical circuits (Shipstone, 1985). The studies undertaken by Piaget and his co-workers also serve as a rich source of insights into the developmental paths in children's thinking. Although it would be a dangerous oversimplification to suggest that all children follow the same route in their understanding of particular notions, there appear to be general trends in the way certain notions are constructed which could provide very useful information for curriculum development.

These studies focus on the change in students' qualitative reasoning. We might ask what this has to do with performance in the ability to understand and use the formal mathematical relations which characterize physics theory? Here we make two points. The first is to indicate that we know that qualitative thinking plays an important role in much numerical problem-solving in physics. Studies that compare the performance of experts and novice problem-solvers in physics show that experts first redescribe the problem in qualitative ways in terms of physics concepts prior to attempting to generate an answer (Larkin, 1983). Students may solve a quantitative problem incorrectly, not because they cannot manipulate the mathematical relationships but because of underlying conceptual difficulties, (Gamble, 1986).

The second point concerns our knowledge of the development of children's mathematical ideas. This is an area of research which would also need to be taken into account in constructing a curriculum is in keeping with developmental features.

Although, as outlined above, some useful basic research has been done, in general we are at an early stage in understanding how scientific concepts are constructed and in particular how formal mathematically based physics knowledge relates to intuitive understanding.

## *Differences in the structure and relationship between ideas*

Scientific thinking differs from everyday thinking not only in the conceptions used. It differs also in the ways ideas are related and the very nature of what is meant by explanation.

Physics is characterized among other things by the formal system of relationships that have been established between variables. An illustration of one representation of such relationships in the area of elementary Newtonian mechanics is given in Figure 3.

Concepts such as mass, velocity and momentum have meaning in terms of the formal relationships between them. They also have meaning for any individual in terms of the multiple ways the concepts relate to events and the experiences and episodes they evoke. However, it is possible to operate within the formal system without reference to events.

Everyday thinking is not characterized by such a formal system and thinking is characteristically closely tied to experiences. In learning physics, students have to learn how to redescribe physical situations in terms of the formal system, then perform manipulations within that system, after which they have to redescribe the product of those manipulations in terms of the physical situation again.

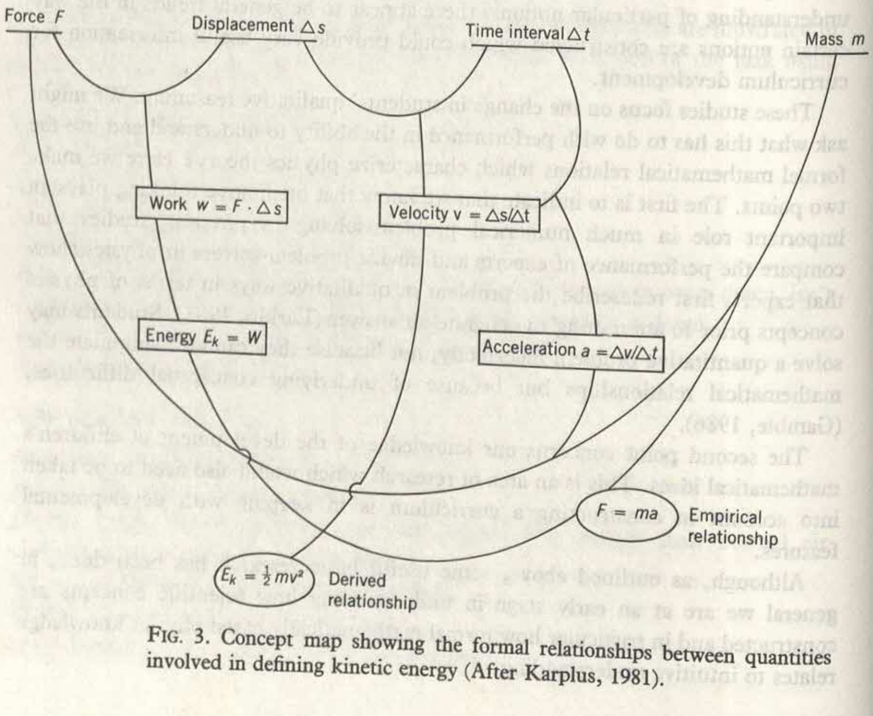

FIG. 3. Concept map showing the formal relationships between quantities involved in defining kinetic energy (After Karplus, 1981).

An important change that takes place in students' reasoning when learning physics is a change in the criterion used for accepting a particular way of seeing an event. In everyday thinking, events are construed or modelled (often unconsciously) in ways which can be ad hoc. As long as the model 'fits' what is seen to happen, or enables a particular problem to be solved, it is used. Indeed in most cases it is seen as self-evident. In physics, a conscious distinction is made between experience and the abstract formal system used to describe that experience. In addition, the formal system carries great authority. If students cannot fit their observations into the relations which characterize the formal system, then they tend to question the observations or simply acknowledge their lack of ability to bring the formal system to bear on the problem. Where in everyday thinking authority tends to be vested in experience, in physics authority is vested in the formal system. (There are both psychological and sociological aspects of this, which it is not possible to develop here.)

There is a further distinction between everyday and scientific reasoning which also relates to the place of formal models in science. In the previous section it was indicated that the nature of children's explanations differs in substantial ways from scientific explanation. We have seen how children tend to seek explanations in terms of chains of cause and effect. In school science, on the other hand, students are presented with explanations in terms of models, either mathematical (as in the case of mechanics) or, in some cases, analogical (as in the case of the 'perfect gas').

What we are doing when we 'explain something' clearly changes in a profound way. Learning physics involves understanding that this is in the nature of the discipline. If such issues are assumed as implicit, we are likely to see students attempting to understand in causal terms and hence having difficulties.

## *Differences in purposes between everyday and scientific thinking*

The third basic difference between children's ideas and scientific theory is a difference in purpose. Children and adults in many everyday situations use simple conceptual schemes in solving a practical problem (be it fault-finding in an electric circuit, making decisions about domestic energy policy or building a garden shed). The criterion for the value and usefulness of such schemes is whether they work in the situations of interest. In this sense, everyday ideas are more like technological tools to help us solve problems of concern to us. Here we must recognize not only that such everyday ideas are different from those taught in science courses, but in many cases they do work for the purposes intended. Electricians probably do not use sophisticated theories about current in electricity in tracing faults; steelmakers' notions of heat are perhaps interestingly reflected in the use of such terms as 'soaking pits', where steel bars are heated to the required temperature before rolling. Indeed there is an interesting literature developing in the area of everyday science notions of adults (Rogoff and Lave, 1984).

Such studies indicate that 'theories' other than those propagated through school science are being used, and in some cases are being used to effect, in people's everyday lives. We might pause for a moment and reflect on whether teaching ideas that are going to be useful to people necessarily mean teaching the scientific view. I think not. The question curriculum developers might ask here is what ideas are actually functional to pupils in dealing with daily life situations.

If on the other hand we wish to promote an understanding of the ideas scientists use, as opposed to functional knowledge, the differences in criteria used for accepting and rejecting ideas need to be explored. The nature of the scientific quest itself, the search for coherence, parsimony and elegance, needs to be made an explicit part of the teaching programme.

To summarize, then, changing students' thinking so that they think scientifically certainly means changing their conceptions. However, it is not just a change in the content of students' ideas that is required if they are to think scientifically. It involves an appreciation of the nature of scientific reasoning in terms of the relationship between theory or models and experience. Perhaps even more fundamentally it requires students to appreciate the epistemological commitments of scientists.

## Towards a developmental view of curriculum planning

### *Introduction*

The differences between children's ideas and scientific thinking gives us some indication of the types of changes and the magnitude of those changes, which we may be attempting to promote in young people's understanding during their school years. In this section, we consider how such changes might be promoted and the implications for curriculum planning.

### *Learning as conceptual change*

The issue of how conceptual change can be promoted is currently a matter of interest and a subject of research. Let us examine briefly some options.

The first option, one which has been practised widely, is to ignore students' prior ideas and to base the teaching solely on the structure of the subject itself. The idea is that if the structure of a topic, whether it be optics, dynamics or electromagnetism, is presented in a well-organized way in terms of the formal relationships between the science concepts, then this will enable students to develop this conceptual structure themselves. We now know the problems inherent in such an approach. Researchers notice for example that prior ideas may persist through to university level despite such instruction (Viennot, 1979; Reif, 1986). The approach also tends to lead to a partitioning of students' thinking; school knowledge is separated from everyday knowledge and only used to answer 'school type' problems and examination questions (Solomon, 1983). There may also be a group of students for whom the ideas they are taught are so different from their own that they see no reason to take the lessons seriously. Science, for them, is just a meaningless set of rules and relationships which seem to bear no relation to their experience, and so they opt out of learning.

An alternative to 'telling', whether through lectures, textbooks or demonstrations, is to give students opportunities to 'find out for themselves' and to base students' learning on empirical experience. Unfortunately such 'discovery methods' have been seen to founder, not because students are unable to investigate for themselves and make inferences from their observations—they are quite able to do this—but because they do not necessarily 'discover' what was intended (Atkinson and Delamont, 1976; Koertge, 1970; Wellington, 1981). Experience in itself is not enough. Indeed in many cases, empirical evidence is used by students to reinforce their prior notions rather than to encourage change (Gunstone and White, 1981; Rowell and Dawson, 1983).

A third approach to the problem is currently being explored. This assumes that students' prior ideas are a necessary starting point and instruction should be designed so as to enable these ideas to develop and change. The process of conceptual change has been analysed from a number of theoretical perspectives (West and Pines, 1985) and a number of studies investigating ways of promoting conceptual change in the science classroom have been reported (Nussbaum and Novick, 1982; Hewson and Hewson, 1984 ; Champagne et al., 1982; Osborne and Freyberg, 1985). Features of these approaches include: (a) opportunities for students to make their ideas explicit; (b) opportunities for clarification and exchange of ideas; (c) experiences that confront students' current notions (conflict situations); (d) opportunities for the input of new ideas or for the restructuring of ideas by the teacher; and (e) opportunities to use concepts in a range of situations. Perhaps the most significant feature of these approaches is the emphasis placed on students' becoming more aware of their own learning and extending their everyday reasoning so it can be used with confidence in a wider range of situations.

## *Designing learning programmes*

In order to translate the developmental curriculum into practice, decisions have to be made about appropriate learning activities and the way these may be sequenced as children get older.

An important principle in making this translation is to start with the assumption that 'meaning is derived from episodes' (Jung, 1985). It is the specifics of a situation that tend to be remembered. If dynamics is taught through experiences with dynamics trolleys and ticker tape, it is the specific features of the trolleys and tapes that are remembered by most pupils. It is well known that if children are introduced to simple electric circuits using circuit boards, they do not necessarily generalize the principles to other simple electric circuits with different superficial appearances or geometries (Gott, 1984). Various developments in cognitive psychology support the view that much of human learning is context-dependent rather than being characterized by general structures or strategies (Donaldson, 1978; Wason and Johnson-Laird, 1972). If it is the case that children remember the specifics of a learning situation and only generalize or transfer ideas with difficulty, then this means that we need to give greater consideration to the value to the learner of the actual contexts in which learning takes place. This is one of the arguments behind a n umber of more socially relevant science schemes and is well illustrated in the Netherlands PLON curriculum (with titles for units such as 'Traffic', 'Bridges', and 'Electricity in the Home').

Giving consideration to the experiences and phenomena that children will be exposed to in the learning programme is by no means a novel perspective for science educators. Experiential learning has been prominent in many science curriculum-development programmes. In considering the place of experiences in a developmental curriculum, however, a great deal more thought and research effort may need to go into the choice of appropriate experiences for particular age groups and the sequencing over years of the domains of those experiences. In doing this, there are a number of issues which we might bear in mind:

1. What are the domains of experience which children at a particular age are intereted in exploring? (Sand, water and play-dough provide fascinating and valuable learning experiences for children in the early years of primary school, but would not be taken seriously by older children.) Older secondary-school children may be becoming aware of some of the effects of science in society and feel concern over issues such as nuclear power and pollution.
2. Within these domains, what are the questions children themselves are interested in? (Many of the ideas in secondary-school physics courses are presented to children before they have even appreciated there is a question to be asked.)
3. What are the domains of experience that will enable children to obtain knowledge that they see as useful to them and which provide useful learning outcomes in themselves? (A unit of work on photography may give great satisfaction to students in terms of learning new skills and producing a product for their efforts—their own photographs.) They may also appreciate something about optics and the behaviour of light through studying the unit, but this may not be the main purpose of the activity.
4. How might experiences be chosen and sequenced in order that they give

students an opportunity in the long term to construct some of the important conceptual ideas of science?

What is being proposed here is a view of the curriculum which is structured in the first instance around domains of experience rather than the theoretical concepts of a scientific discipline. Each domain, topic or unit of work should correspond with the children's interests and provide what they see as worthwhile learning outcomes. The topics would need to be planned and sequenced, taking children's conceptual development into account. Lastly, and this presents a particular challenge, the sequence would need to facilitate the progressive construction by students of ideas in line with formal scientific principles. Children will not necessarily invent such ideas; they may need to be formally introduced. However, they are more likely to be assimilated when they are seen to be useful. Some of the issues involved in taking such a phenomenological approach are explored by Guidoni (1986) in the context of learning about energy.

## Curriculum development as a research programme

### *Introduction*

Developing a curriculum, or indeed a short sequence of work, which satisfies the points made above may draw on our current knowledge of learning in science and on our knowledge of the subject itself. However, we would be foolish to think that we could necessarily promote the intended learning by planning such activities in an *a priori* way.

Classrooms are immensely complex places. Producing effective learning activities entails studying the learning promoted in classroom environments and modifying materials and teaching strategies to enhance the learning that goes on. The development and evaluation of teaching materials is itself a research activity.

An current example of a way of doing this is provided by the Children's Learning in Science Project at the University of Leeds (Driver and Oldham, 1986).

### *Outline of the project*

The Children's Learning in Science Project bases its work on a constructivist view of learning. It has produced and evaluated teaching approaches aimed at improving secondary-school students' understanding in three conceptual areas in science (particulate theory of matter, energy and plant nutrition).

The process of curriculum development being adopted is one involving a cyclical process of design, teaching, monitoring, reflection, evaluation and revision in the light of feedback on the learning that has taken place. We have worked on the premiss that all participants in the exercise, students, teachers and researchers, have their personal goals and perspectives, which in turn influence the way they construe and act in situations. Students' learning depends on how they interpret the learning tasks presented. The way teachers present learning tasks and how they interact in the classroom also depends on how they construe the programme of tasks and interpret the ongoing classroom interactions. For this reason, teacher development is seen to be part of curriculum development.

### *The programme for curriculum development*

The project was started by inviting secondary-school science teachers to participate as collaborators in a programme of curriculum development based on constructivist principles. About forty science teachers in three working groups have been involved in the programme over the last two years.

The initial task undertaken by all the teachers involved was to teach one of the selected topics using their traditional method of teaching. The learning taking place in their classrooms was monitored over this period using diagnostic tests, by tape-recording lessons and by asking teachers and students to keep diaries.

The information obtained from selected classes was written up as case-studies (Bell et. al., 1985; Wightman et al., 1986; Brook and Driver, 1986). These were used by the working groups as a basis for reflection on learning and teaching while planning revised teaching schemes.

Information of four main types was considered as a basis for devising the revised schemes: decisions on content; information on students' prior ideas; perspectives on the process of learning; and practical knowledge of students, classrooms and schools. The model governing the development process itself is shown in Figure 4.

### Content

In making decisions about content, the groups produced a document outlining the ideas it was hoped students would be able to construct as a result of the learning sequence and the contexts in which these could be introduced. In a unit concerned with the teaching of energy, for example, the context selected was the domestic environment, paying bills, using fuels efficiently, etc. Opportunities were given to introduce and use certain ideas in relation to these contexts such as energy transfer, transformations, degradation, dissipation and efficiency.

### Students' prior ideas

Information about students' prior ideas was obtained through a review of relevant literature, from earlier studies conducted by the project and from the case-studies of current practice. This information provided guidance on those aspects of

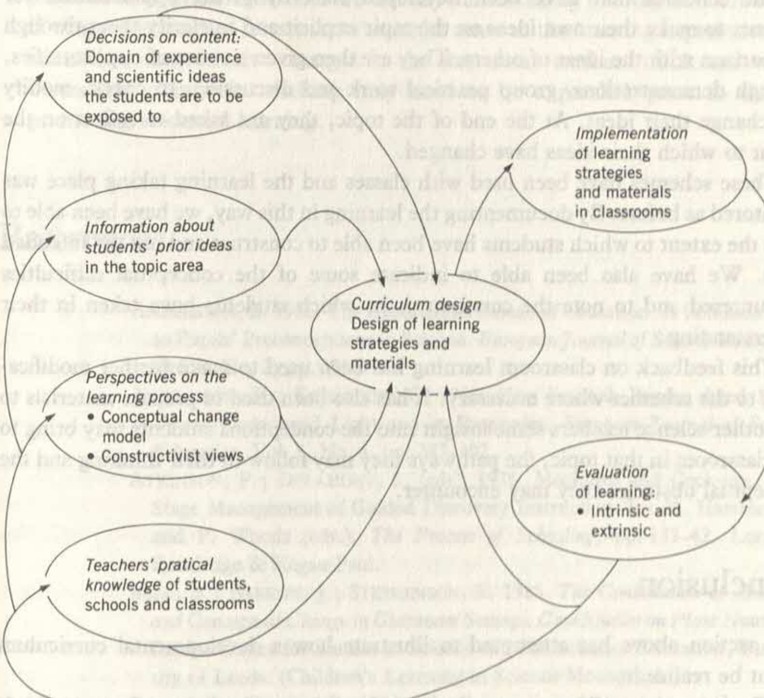
*Decisions on content:*
Domain of experience and scientific ideas the students are to be exposed to
*Information about students' prior ideas* in the topic area
*Perspectives on the learning process*
• Conceptual change model
• Constructivist views
*Teachers' pratical knowledge* of students, schools and classrooms
*Implementation* of learning strategies and materials in classrooms
*Curriculum design*
Design of learning strategies and materials
*Evaluation* of learning:
• Intrinsic and extrinsic

FIG. 4. A constructivist model for curriculum development.

students' thinking that are resistant to change and that are likely, therefore, to need to be addressed explicitly (such as the notion that atoms and molecules have the properties of bulk materials that is, they get hot, expand, melt, etc. or that energy can disappear, for example, when a sliding object stops). Knowledge of these ideas also provided indications as to the kinds of activities which might challenge students' current ideas.

## Perspectives on learning

Perspectives on the learning process were considered through the discussion of selected papers and through discussion of issues which emerged from the study of current practice.

## Practical knowledge of schools

In devising the revised scheme, teachers' own practical knowledge of the types of tasks students would engage in and the resources available was drawn on.

The schemes that have been developed start by giving opportunities for students to make their own ideas on the topic explicit and to clarify them through comparison with the ideas of others. They are then given a series of opportunities, through demonstrations, group practical work and discussion, to check, modify and change their ideas. At the end of the topic, they are asked to reflect on the extent to which their ideas have changed.

These schemes have been used with classes and the learning taking place was monitored as before. By documenting the learning in this way, we have been able to trace the extent to which students have been able to construct and use the intended ideas. We have also been able to indicate some of the conceptual difficulties encountered and to note the common paths which students have taken in their understanding.

This feedback on classroom learning has been used to make further modifications to the schemes where necessary. It has also been used to prepare materials to give other science teachers some insight into the conceptions students may bring to the classroom in that topic, the pathways they may follow in their thinking and the conceptual obstacles they may encounter.

## Conclusion

The section above has attempted to illustrate how a developmental curriculum might be realized.

The key point in the argument here is what we mean by the curriculum. If it is viewed as a body of knowledge to be transmitted to a learner, then its development may be seen as unproblematic. We simply decide what it is that people need to know. The problem, as we have seen with this, is that there can be serious disparities between our educational objectives and the actual learning outcomes. This chapter, however, is based on a different premises about teaching and learning. It is assumed that individuals construct their own knowledge; the curriculum is therefore perhaps more helpfully seen as a set of experiences which enables students to develop the skills or ideas intended. Adopting this view has a number of consequences:

It means that curriculum developers require knowledge not only of the subject to be taught, but on the way learning takes place. Earlier sections of this chapter gave some indication of the information we have about students' thinking and learning. There are however many open questions that remain.

Rather than being seen as an *a priori* category, the curriculum as a set of activities becomes a proper subject for inquiry. It is only through careful monitoring and feedback of materials in use that we will be able to produce learning activities which are adapted to students' ways of thinking.

Teacher development is an aspect of curriculum development. The experiences students have in the classroom are directly influenced by the way teachers work. Giving opportunities for students to make sense of the learning experiences for themselves may involve changes in the way many teachers think and work. Promoting change in teaching may need to be a parallel quest to that of promoting students' learning.

## References

Andersson, B. 1986. The Experiential Gestalt of Causation: A Common Core to Pupils' Preconceptions in Science. *European Journal of Science Education*, Vol. 8, No. 2, pp. 155–71.

Andersson, B.; Karrquist, C. 1983. How Swedish Pupils, Aged 12–15 Years, Understand Light and its Properties. *European Journal of Science Education*, Vol. 5, No. 4, pp. 387–402.

Atkinson, P.; Delamont, S. (eds). 1976. Mock-ups and Cock-ups: The Stage Management of Guided Discovery Instruction. In: M. Hammersley and P. Woods (eds.), *The Process of Schooling*, pp. 133–42. London, Routledge & Kegan Paul.

Bell, B.; Barron, J.; Stephenson, E. 1985. *The Construction of Meaning and Conceptual Change in Classroom Settings. Case Studies on Plant Nutrition.* Leeds, Centre for Studies in Science and Mathematics Education, University of Leeds. (Children's Learning in Science Monograph.)

Brook, A.; Driver, R. 1986. *The Construction of Meaning and Conceptual Change in Classroom Settings. Case Studies in the Learning of Energy.* Leeds, Centre for Studies in Science and Mathematics Education, University of Leeds. (Children's Learning in Science Monograph.)

Champagne, A.B.; Klopfer, L.E.; Gunstone, R.F. 1982. Cognitive Research and the Design of Science Instruction. *Educational Psychologist*, Vol. 17, pp. 31–53.

Claxton, G. 1986. Mini Theories: A Preliminary Model for Learning Science. London, Centre for Educational Studies, King's College London, Chelsea Campus. (Unpublished MS.)

DiSessa, A. 1983. Phenomenology and the Evolution of Intuition. In: D. Gentner and A.L. Stevens (eds.), *Mental Models*, pp. 15–33. Hillsdale, N.J., Lawrence Erlbaum Associates.

Donaldson, M. 1978. *Children's Minds.* London, Croom Helm.

Driver, R. 1983. *The Pupil as Scientist?* Milton Keynes, Open University Press.

Driver, R.; Guesne, E.; Tiberghien, A. (eds). 1985. *Children's Ideas in Science.* Milton Keynes, Open University Press.

Driver, R.; Oldham, V. 1986. A Constructivist Approach to Curriculum Development in Science. *Studies in Science Education*, Vol. 13, pp. 105–22.

DUIT, R.; JUNG, W.; VON RHONECK, C. (eds). 1985. *Aspects of Understanding Electricity*. Kiel, Institut für die Pädagogik der Naturwissenschaften.

ENGEL CLOUGH, E.; DRIVER, R. 1985*a*. Secondary Students' Conceptions of the Conduction of Heat: Bringing together Personal and Scientific Views. *Physics Education*, Vol. 20, pp. 176–82.

——. 1985*b*. What Do Children Understand about Pressure in Fluids? *Research in Science and Technology Education*, Vol. 3, No. 2, pp. 133–44.

——. 1986. A Study of Consistency in the Use of Students' Conceptual Frameworks Across Different Task Contexts. *Science Education*, Vol. 70, No. 4, pp. 473–96.

ERICKSON, G.L. 1979. Children's Conceptions of Heat and Temperature. *Science Education*, Vol. 63, No. 2, pp. 221–30.

ERICKSON, G.L.; TIBERGHIEN, A. 1985. Heat and Temperature. In: R. Driver, E. Guesne and A. Tiberghien (eds.), *Children's Ideas in Science*, pp. 52–66. Milton Keynes, Open University Press.

GAMBLE, R. 1986. Simple Equations in Physics. *European Journal of Science Education*, Vol. 8, No. 1, pp. 27–37.

GOTT, R. 1984. *Electricity at Age 15: Science Report for Teachers*, No. 7. London, Department of Education and Science.

GUESNE, E. 1984. Children's Ideas about Light. In: E.J. Wenham (ed.), *New Trends in Physics Teaching*. Vol. 4, pp. 179–92. Paris, Unesco.

GUNSTONE, R.; WHITE, R. 1981. Understanding of Gravity. *Science Education*, Vol. 65, No. 3, pp. 291–9.

GUIDONI, P. 1986. A Phenomenological Approach to the Development and Differentiation of Energy Ideas. In: R. Driver and R. Miller (eds.), *Energy Matters*, pp. 103–32. Leeds, Centre for Studies in Science and Mathematics Education, University of Leeds.

HAWKINS, D. 1978. Critical Barriers in Science Learning. *Outlook*, Vol. 29, pp. 3–22.

HELM, H.; NOVAK, J. 1983. *Proceedings of the International Seminar: Misconceptions in Science and Mathematics*. Ithaca, N.Y., Cornell University.

HEWSON, P.; HEWSON, M. 1984. The Role of Conceptual Conflict in Conceptual Change and the Design of Science Instruction. *Instructional Science*, Vol. 13, pp. 1–13.

JUNG, W. 1985. Uses of Cognitive Science to Science Education. Paper presented at the ATEE Symposium on the Implications of Cognitive Science for the Education of Science Teachers, Kiel, August 1985.

JUNG, W.; PFUNDT, H.; RHONECK, C. 1982. *Problems Concerning Students' Representation of Physics and Chemistry Knowledge*. Ludwigsburg, Pädagogische Hochschule Ludwigsburg.

KARMILOFF-SMITH, A.; INHELDER, B. 1976. If You Want to Get Ahead, Get a Theory. *Cognition*, Vol. 3, pp. 195–213.

KARPLUS, R. 1981. Educational Aspects of the Structure of Physics. *American Journal of Physics*, Vol. 49, No. 3, pp. 238–41.

KOERTGE, N. 1970. Toward an Integration of Content and Method in the Science Curriculum. *Curriculum Theory Network*, No. 4, pp. 26–44.

LARKIN, J.H. 1983. The Role of Problem Representation in Physics. In: D. Gentner and A.L. Stevens (eds.), *Mental Models*, pp. 75–98. Hillsdale, N.J./London, Lawrence Erlbaum Associates.

MILLER, S; ROBINSON, D.; DRIVER, R. 1985. Secondary Students' Ideas about Air and Air Pressure. In: B. Bell, D.M. Watts and K. Ellington (eds.), *Learning, Doing and Understanding in Science*, pp. 58–63. London, Secondary Science Curriculum Review.

NUSSBAUM, J.; NOVICK, S. 1982. Alternative Frameworks, Conceptual Conflict and Accommodation: Towards a Principled Teaching Strategy. *Instructional Science*, Vol. 11, pp. 183–200.

OSBORNE, R.; FREYBERG, P. (eds.). 1985. *Learning in Science*. Auckland/London, Heinemann.

REIF, F. 1986. *Interpretation of Scientific or Mathematical concepts; Cognitive Issues and Instructional Implications*. Berkeley, Calif., Department of Physics and School of Education, University of California. (Report No. CES–1.)

ROGOFF, B.; LAVE, J. (eds.). 1984. *Everyday Cognition. Its Development in Social Context*. Cambridge, Mass./London, Harvard University Press.

ROWELL, J.A.; DAWSON, C.J. 1983. Laboratory Counter-Examples and the Growth of Understanding in Science. *European Journal of Science Education*, Vol. 5, No. 2, pp. 203–15.

SÉRÉ, M.-G. 1982. A Study of Some Frameworks Used by Pupils Aged 11 to 13 Years in the Interpretation of Air Pressure. *European Journal of Science Education*, Vol. 4, No. 3, pp. 299–309.

SHIPSTONE, D. 1985. Electricity in Simple Circuits. In: R. Driver, E. Guesne and A. Tiberghien (eds.), *Children's Ideas in Science*, pp. 33–51. Milton Keynes, Open University Press.

SJOBERG, S.; LIE, S. 1981. *Ideas about Force and Movement among Norwegian Pupils and Students*. Oslo, University of Oslo. (Institute of Physics Report Series, 81–11.)

SOLOMON, J. 1983. Learning about Energy: How Pupils Think in Two Domains. *European Journal of Science Education*, Vol. 5, No. 1, pp. 49–59.

STRAUSS, S.; STAVY, R. 1982. U-shaped Behavioral Growth: Implications for Theories of Development. In: W. Hartup (ed.), *Review of Child Development Research*, Vol. 6. Chicago, University of Chicago Press.

TIBERGHIEN, A. 1986. Difficulties in Concept Formation. In: D. Layton (ed.), *Innovations in Science and Technology Education*, Vol. 1, pp. 95–108. Paris, Unesco.

VIENNOT, L. 1979. Spontaneous Reasoning in Elementary Dynamics. *European Journal of Science Education*, Vol. 1, No. 2, pp. 205–21.

WASON, P.C.; JOHNSON-LAIRD, P.N. 1972. *Psychology of Reasoning*. London, Batsford.

WELLINGTON, J.J. 1981. What's Supposed to Happen, Sir? Some Problems with Discovery Learning. *School Science Review*, Vol. 63, No. 222, pp. 167–73.

WENHAM, E.J. (ed.). 1984. *New Trends in Physics Teaching*. Vol. 4, Paris, Unesco. (The Teaching of Basic Sciences).

WEST, L.; PINES, A.L. (eds.). 1985. *Cognitive Structure and Conceptual Change*. London, Academic Press.

WIGHTMAN, T.; GREEN, P.; SCOTT, P. 1986. *The Construction of Meaning and Conceptual Change in Classroom Settngs. Case Studies on the Particulate Theory of Matter*. Leeds, Centre for Studies in Science and Mathematics Education, University of Leeds. (Children's Learning in Science Monograph.)

WITTROCK, M.C. 1974. Learning as a Generative process. *Educational Psychology*, Vol. 11, pp. 87–95.

# Part III

# Interdisciplinarity in science and technology education

# Introduction

Interdisciplinarity in science education was the subject of five volumes published by Unesco at intervals throughout the 1970s (Unesco 1969–70, 1973, 1974, 1977, 1979). These explored many aspects of the teaching of integrated science, not least the difficult problem of educating teachers for the task (e.g. Unesco, 1974). Exhaustive though these contributions were, it is clear from the four chapters in this part that the problems of interdisciplinary teaching continue to invite definition and analysis, to say nothing of solution.

As Joyce Glasgow reminds us, the term 'interdisciplinarity' has many shades of meaning. She also makes the important point that teacher-education strategies have in the past often resulted more from the specific problems of particular fields such as agriculture, environmental education and integrated science than from any general analysis of what interdisciplinarity entails. One consequence of this has been a primary emphasis on giving teachers the confidence to deal with unfamiliar subject matter. Jakes Swartland, for example, writes of the ways in which panels of science teachers related science to everyday experiences and reduced the factual content so that it was less frightening at the primary-school level. The panels also produced simply written resource booklets of background information to aid unqualified teachers in their attempts to implement the revised syllabus. X. F. Carelse, likewise, emphasizes the need for training workshops and a supporting infrastructure in order to ensure the implementation of the technology-based science syllabus he outlines. The components of this support system include textbooks, teachers' guides, equipment and appropriately designed laboratories and workshops. In their account of the most ambitious—in terms of subject matter—of the three school curriculum innovations described in this section, the attempt to integrate the natural sciences with other school subjects, Lazarov and Golovinsky acknowledge that teachers cannot be expected to demonstrate encyclopedic knowledge; an admission of ignorance is acceptable. Nevertheless, the Bulgarian project requires the teacher to attempt to repair any knowledge deficiency so that pupils' questions can be answered in a subsequent lesson.

As authors in this part and Part IV illustrate, the pressures for interdisciplinary curriculum innovations are strong. Indeed integrality was identified in the first chapter of Part I as an emergent theme of this volume. Consideration of the case of technology, however, does suggest strategies for achieving interdisciplinarity and coherence in the curriculum other than the marrying of subject matter and the breaching of traditional subject boundaries by each teacher on an individual basis. The problem is less one of correlating the teaching of two or three related knowledge areas, such as biology, chemistry and physics, than of bringing into a productive relationship diverse knowledge, skills and experience in order to solve a problem or create an artefact. Modern technology is almost entirely a collective enterprise. In such collaborative group activities, organizational aspects are as crucial to success as the scientific principles and economic considerations involved.

What is being suggested, therefore, is the adoption in schools of organizational structures and management strategies that oblige teachers to move from their traditional isolation and which support them in collaboration over the design and delivery of interdisciplinary learning experiences. Enabling measures such as the timetabling of a group of collaborating teachers so that they can plan and teach together would seem to be a minimal requirement. The management of space as well as time, for example by room allocations that assist collaboration, is also important. In some cases, joint ownership of resources has fostered fruitful co-operation, as when software such as a graphics package has been shared between a number of departments in a secondary school. On the other side of this coin, however, the locating of administrative responsibility for a network of computers in, say, a mathematics department, could make it more difficult for others, such as teachers of environmental science and biology, to gain access to it.

Such structural measures, while undoubtedly important and without which interdisciplinary collaboration can be severely handicapped, are only part of the story, however. In the limit, effective collaboration between teachers depends on the establishment of good personal relationships between individuals and a shared sense of meaning of, and commitment to, the change. No legislation can ensure the former, but the chapters that follow contain suggestions for the latter. The subject panels of serving teachers, of which Swartland writes, were convened in the belief that change would be more readily accepted by teachers if they themselves had some sense of ownership of the innovations rather than having it externally imposed on them. The case-studies which constitute the preferred mode of teaching the technology-based science syllabus described by Xavier Carelse were selected on the basis of relevance to those involved. The secondary-school teachers taking part in the Bulgarian experiment in integration participated in annual conferences where they could share their interdisciplinary experiences with others.

If change is to be successful it 'must be construed as "a communal venturing forth"... on the basis of a common knowledge of what is at stake, a common sense of purpose and a common understanding of the principles that inform new practices' (Ruddock, 1986, p. 108). Curriculum change, including a change in teaching styles, is then to be viewed as a cultural change in the sense that it entails teachers' modifying the ways in which they have previously made sense of their work and the meanings they have given it. Bearing in mind the long history of individualistic modes of operating by teachers, especially in secondary schools, a change to collaborative working amounts to a major shift in the culture of teaching, the magnitude of which we should not underestimate.

## References

RUDDOCK, J. 1986. Curriculum Change: Management or Meaning? *School Organization*, Vol. 6, pp. 107–44.

UNESCO. 1969–79. *New Trends in Integrated Science Teaching*: Vol. 1, prepared by P.E. Richmond, 1969–70; Vol. 2, edited by P.E. Richmond, 1973; Vol. 3: *Education of Teachers*, edited by P.E. Richmond, 1974; Vol. 4, edited by D. Cohen, 1977; Vol. 5, edited by J. Reay, 1979. Paris, Unesco. (The Teaching of Basic Sciences.)

# *Interdisciplinarity in the teaching of science during the first nine to ten years of basic education*

Jakes Swartland

## Introduction

Science education, like other aspects of education, has been affected by the trend away from so-called 'élitist minority education' to the mass democratization of education. In developing countries, rapid expansion at both primary- and secondary-school levels has brought new problems into focus. To general concerns about the disparity between urban and rural education and unemployed young school-leavers have been added more specific ones, such as the lack of qualified teachers, inadequate teaching facilities and a shortage of teaching materials. These are typical of problems which, in one way or another, have affected the development of science education in many countries. Furthermore, since the mid-1970s, assertions such as the following have become all too familiar in the committee rooms of curriculum centres:

Schools are too separated from the world of work.

Children are not being taught about the real practical world.

There is a gap in quality levels and educational oportunities between urban and rural schools.

Science education in primary schools should prepare children for life in the physical and social environment which they will experience after they leave school.

Starting from these diagnoses, a number of southern African countries, including Botswana, Lesotho and Swaziland, set up science panels composed of teachers, education officers and lecturers from teacher-training colleges and universities. Their task was to scrutinize existing syllabuses in order to identify those topics and activities which might be retained or modified to prepare schoolchildren more adequately for survival in the real world. Topics considered inappropriate were discarded and replaced by more relevant ones. A list of topics was drawn up which served as the basis for revised syllabuses that attempted to capitalize upon the children's experiences and interests. The intention was that learning activities would be developed around these topics to lead children to a better understanding of themselves and their environment. Hence such words and phrases as 'integration', 'environmental science', 'multi-strand science' and 'interdisciplinarity of science' began to assume increasing prominence in curriculum documents.

## Statements of aims and objectives

In examining the various syllabuses for basic education in the countries of southern Africa we notice that, although the mode of approach is described differently (e.g. topic, problem-solving, inquiry, child-centred), there are many similarities in the aims and objectives.

There is, for example, widespread recognition of the importance of giving pupils genuine scientific experiences involving observation, experimentation, data collection and analysis, and hypothetico-deductive thinking. Additionally, however, there is an emphasis on acquisition of knowledge and skills which are useful both at a personal level in connection with employment or as a foundation for further study and more generally in relation to the development of the social and economic life of the community. The objectives of primary-school science education in Lesotho, for example, include reference to school-leavers being able to perform scientific operations which will enable them to earn a living and become useful members of society. At the secondary-school level, they should 'be aware of the importance of science and technology in the development of Lesotho' (Lesotho Ministry of Education, 1986). Similarly, the Swaziland Integrated Science Programme emphasizes the learning by pupils of useful scientific facts and concepts concerning their environment (Swaziland Ministry of Education, 1986).

At a Unesco training workshop on the development of teacher-support material in integrated science, held at Gaborone, Botswana, in 1984, the following aims of integrated science at junior secondary-school level were suggested by one contributor (Kahn, 1984).

To learn how to observe, experiment and carry out systematic inquiry.
To study science with the goal of a healthy life in harmony with nature.
To understand the impact of science and technology on work and leisure in a democratic society.
To study that part of science relating to the local reality (for example, subsistence farming, cattle ranching, mining and slow industrial growth in a dry harsh environment are characteristics of Botswana).
To appreciate the technological part of the national cultural heritage.

These have much in common with aims which are at least implicit in science syllabuses in countries such as Botswana, Lesotho, Swaziland, Zimbabwe and

Zambia. There is agreement here with Souchon's (1985, p. 537) assertion that 'In order to decide on the choice of subject-matter for scientific curricula . . . it would be worth while considering what role scientific education might have in a person's later life.' One could go further and argue that science education should provide each pupil with a survival kit which would be of use at whichever point he or she leaves the formal education system.

## What to teach and how to teach it

Science curriculum developments in Europe and North America have had a considerable influence on the content of science courses in many developing countries. Furthermore, for most, if not all, of the latter, the requirement for success in external examinations still remains one of the most important influences on the content of science lessons. Even at the primary-school level, there can be pressure to include topics because they contribute to the foundation necessary for further studies leading to external examinations. Writing about science education in Asian countries, Winter (1970) has stated that 'examination reform is perhaps the largest single step towards more effective instruction'. His conclusion is equally applicable to many African countries, though some are now moving towards a reformation of the examination system to bring it into greater conformity with the new aims of science education.

During the late 1960s and early 1970s, there was a worldwide movement towards the integrated approach to the teaching of science in which African education systems participated. By the mid-1970s, most African countries had adopted, or were in process of adopting, an integrated science curriculum, especially at primary- and lower-secondary-school levels. There were, however, considerable problems of implementation. These were concerned not only with the content and pedagogy of such courses, but also with the supply of teachers able to handle integrated science with confidence and the lack of suitable teaching and learning materials for both teachers and pupils. Given these formidable constraints, it is not surprising to find, for example, the Zimbabwe Secondary School Science Project aiming initially at: (a) designing a course that can satisfactorily be taught by teachers who might not have had a great deal of experience in teaching science; and (b) providing a course which is economically realistic and can be taught without the aid of a purpose-built laboratory.

Many southern African countries tackled the problem by first setting up what were popularly known as 'subject panels'. These were composed mainly of serving teachers, but also included education officers and lecturers from teacher-training institutions and universities. The rationale for these panels involved two considerations. First, existing curriculum centres did not have the necessary staff to undertake the development adequately within the time available. Hence, a different

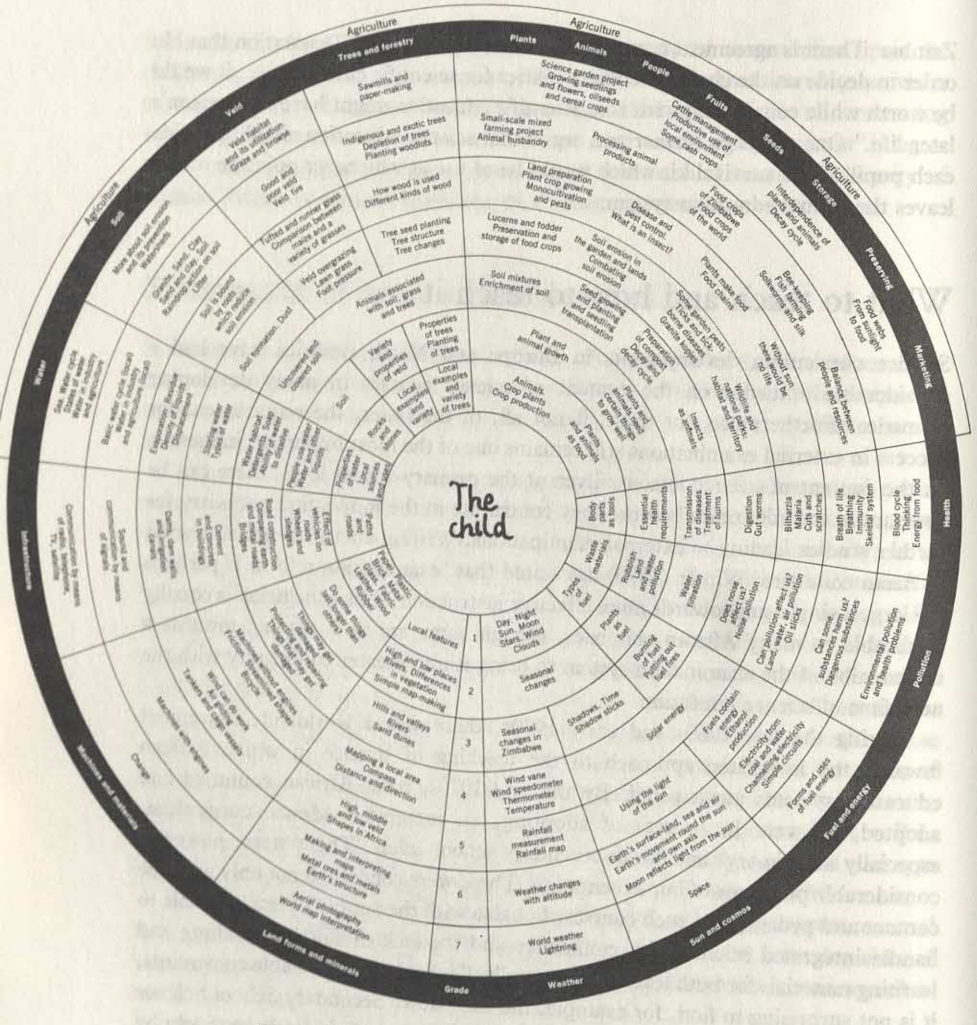

FIG. 1. Links with agricultural science (© Ministry of Education and Culture, Zimbabwe).

process for producing the integrated curriculum was needed. Second, it was believed that a new curriculum would be more readily accepted by teachers if they themselves had been involved in its development and had some feeling of ownership of the innovation rather than experiencing it as something imposed from outside. This strategy of using practising teachers in the determination of what to teach and how to teach it has subsequently become very common in many countries in sub-Saharan Africa.

The task of the science panels was to review existing syllabuses and bring them into line with the new aims for science education. A frequent criticism of some of the syllabuses in use was that they were too heavily laden with content. It was also observed that topics within them were too fragmented and disparate. At the primary-school level, one way forward might have been a severe pruning of the syllabuses and to trust that other problems such as shortage of teachers, insufficiency of equipment and materials, and irrelevance of content to the new aims would somehow be solved. The alternative was to design a completely new primary-school science syllabus, taking into account all the constraints previously identified.

A close scrutiny of syllabuses in use today, compared with the old ones, shows that this latter approach was widely adopted. Syllabuses reflect the current beliefs about the nature of the scientific enterprise and especially about the scientific knowledge that is most important and relevant for young people to understand. The emphasis is upon science as a means of developing self-reliance and of preparing children for useful, productive lives in the adult world. To ensure survival in their own local environment, the approach to learning encourages pupil participation with the intention of developing scientific skills and attitudes necessary for successful problem-solving. The child as learner is the central focal point as the 'summary wheel' from the environmental and agricultural science syllabus for Zimbabwean primary schools, indicates (Fig. 1).

In this, and similar integrated science courses, the stress is on the direct experience of the pupils. They do the observing, collecting and recording of data; discussion takes place throughout and there is a lot of activity. The syllabus merely gives the teachers suggestions for making science lessons more enjoyable and relevant. It provides them with a resource bank of ideas from which they can select activities and experiences meaningful to their pupils. Indeed, the role of the teacher has changed from that of a provider of knowledge to that of a facilitator of learning. A typical primary or junior-secondary school science lesson today in southern African schools should have groups of children clustered round a tree or a pond or building, with pencil and paper in their hands, in contrast with children sitting in rows of desks facing a teacher holding chalk and a duster.

Topics around which the learning is organized are varied and include soil, water, weather, landforms and minerals, trees and forestry, animals, machines and materials, diseases, desertification and pollution. As an example of how one teacher in Zimbabwe dealt with the last of these topics, one which appears in primary, junior secondary and Ordinary(O)-level syllabuses, a project called *Operation Clean Up* was initiated.[1] Its aims were: (a) to encourage pupils to keep their environment clean; (b) to enable pupils to note the link between classroom theory and practice; and (c) to encourage the integration of different school subjects through a science project.

The teacher's specific objectives required the pupils, by the end of the project, to be able to: (a) collect samples of litter in their environment; (b) identify the different types of items of litter in their school environment; (c) classify the litter collected into different categories; (d) record their findings; (e) discuss the distribution of litter in the school environment; and (f) draw up conclusions and resolutions from their findings about the litter problem in the school environment.

It will be seen that this project could promote creativity and communication (language); involve the collection of news items about litter (current affairs); and require the drawing of a plan of operations including the school and its environment (geography and mathematics), the classifying of materials found as litter (science) and the recording of data graphically (mathematics). The list could be expanded to include almost every subject in the curriculum. In the same way, other topics could become the focus for interdisciplinary activity by pupils.

The involvement of practising teachers in syllabus construction through their participation in the work of science panels has led to an emphasis on specific scientific topics which might otherwise have been dealt with more summarily or not at all. In 1982, when the Zimbabwean Junior Certificate Science Syllabus was still under discussion, it was reported at one meeting that teachers stressed the need for the inclusion of some sex education in the unit dealing with living cells and reproduction. Similarly, under earth science, it was argued that more detail on acids and alkalis should be included because of their vital role in agriculture and industry. The incorporation of topics such as conservation of natural resources and health and disease was urged, if necessary at the expense of other content deemed less relevant to a country such as Zimbabwe.

One consequence of such localization of science syllabuses is that content may be found to differ somewhat when syllabuses from different countries are compared. The principles of syllabus construction are the same, however. What is included should be relevant and realistic to the pupils; everyday experience and knowledge should be related to the understanding of scientific concepts; and familiar situations should be drawn upon rather than artificial or unrealistic ones. Thus, while in Zimbabwe the importance of acids and alkalis to agriculture and industry is stressed, in Botswana the Junior Secondary Integrated Science Syllabus emphasizes chemicals in the home, their role as solvents and their potential danger as poisons (Botswana Ministry of Education, 1986).

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[1] Further details of Operation Clean Up project are given in *Teachers' Forum*, Vol. 14, No. 9, September 1986, published in Zimbabwe by the College Press Group.

## Who will teach these new syllabuses?

The revised primary-school syllabuses had to be drawn up with the teachers who would implement them very much in mind. Major complaints about the old syllabuses were that they emphasized book-learning and needed teachers with specialist training in science. In the new syllabuses, the intention is that science should be learnt in a well-defined and meaningful context with obvious practical application. The science involved is in no sense inferior to that learnt in academic courses. Furthermore, topics can be extended in scope according to needs. Thus, monopumps can be discussed rather than force pumps; while solar stills for water desalination and photovoltaic pumping are examples of state-of-the-art technologies that can be introduced.

At the primary-school level, the science panels have tried to ensure that science is presented in a less alarming way by reducing the factual content and relating science to everyday experiences and to the child's level of understanding. Such measures make teachers, especially unqualified ones, more comfortable in handling the subject and permit a more play-orientated approach to learning science.

In Botswana, the syllabus was tested in a few selected schools before it was introduced nationally. Suggestions from the trial schools for changes in the syllabus were in some cases incorporated. Thereafter, the panel embarked on the development of support materials which would give teachers ideas and guidance about activities they could undertake with pupils and materials from the local environment they could use. Throughout, emphasis was on the everyday world being a natural science laboratory sufficiently well equipped to assist any science teacher. Learning was not viewed as an activity that could only take place in separate subject compartments, and the issue of subject integration continues to engage the attention of the subject panel. Indeed, the thematic or topic approach to science in primary education has spilled over into lower-secondary education where, for example, the theme 'You and Your Home' includes topics such as 'health of the family', 'the food we eat', 'the importance of personal cleanliness to family health' and the advantages of breast-feeding babies as against the risks of bottle-feeding.

Attempts have been made to provide as much background scientific information as possible so that lack of scientific knowledge does not unduly hamper the use of the syllabus by unqualified teachers. During the trial period in Botswana, the panel embarked on the development of teachers' resource booklets designed to explain scientific concepts used in the syllabus. These were written in such a way that the teachers would not be overwhelmed with technical words and explanations. The resource-book project is still continuing.

One of the major advantages of the reformed syllabuses is the use that is made of the resources of the immediate environment. Nevertheless, there are still certain items of basic equipment that cannot be bought or otherwise obtained locally, which are essential for the implementation of the new schemes. In an attempt to overcome this difficulty, the science panels in some countries have developed an inexpensive science-teaching kit which can be distributed to all schools. The items in this kit have been selected on the basis of the activities in the teachers' guide, thereby ensuring that the essential apparatus is available to all teachers of science. An outstanding example of such a kit is provided by the Zim-Sci materials developed at the University of Zimbabwe. In addition, science education workshops for primary-school teachers have been conducted by panel members throughout the various districts whenever these are requested by regional education officers. These in-service workshops have been an interim measure to help teachers implement the revised syllabuses and to introduce them to ways of teaching that promote up-to-date scientific attitudes in their children. Primary-school teachers in the developing world have always been multidisciplinary teachers. Provided they are adequately prepared and supported, the integrated approach to the teaching of science is a natural development of their well-established practices.

There is evidence in some countries that the response to the new approach has been extremely positive among primary-school teachers and panel members have recorded evidence of dramatic changes in the teaching schemes of some teachers as a result. It is hoped that in the future the combination of readily available teaching and learning materials together with in-service workshop experience will enable even more impressive changes in teachers' approach to be achieved.

## References

BOTSWANA MINISTRY OF EDUCATION. 1986. *Junior Certificate Integrated Science Syllabus*. Gaborone, Ministry of Education.

KAHN, M. 1984. A Relevant Science Education. *Report of the Integrated Science Workshop, Gaborone, Botswana, 1984*. Gaborone, Ministry of Education/Unesco.

LESOTHO MINISTRY OF EDUCATION. 1986. *Integrated Science for Junior Certificate*. Maseru, Ministry of Education.

SOUCHON, C. 1985. Some Thoughts on the New Approaches to Science Education. *Prospects; Quarterly Review of Education*, (Unesco), Vol. 15, No. 4, pp. 535–40.

SWAZILAND MINISTRY OF EDUCATION. 1986. *Integrated Science Programme for Junior Certificate*. Mbabane, Ministry of Education.

WINTER S.S. 1970. *Science Education at the Elementary and Secondary Level in Asia*. (A survey of states and developments prepared for Unesco.) Cited in: *Unesco Handbook for Science Teachers*, p. 82. Paris/London, Unesco/Heinemann, 1980.

# *Technology education in relation to science education*

Xavier F. Carelse

## The missing link

In many countries, science education at secondary-school level would seem to be designed primarily to prepare children for university entrance. It has to provide the foundation for more specialized scientific studies in universities. Its links with technology and with the everyday world are tenuous and ill-defined; children learn very little that is of practical use outside the school laboratory.

Technology education, on the other hand, relates to what we do, to what happens around us. At a recent Unesco International Symposium on the Teaching of Technology within the Context of General Education, the delegates agreed on the following definition of technology (Unesco, 1985, p. 8):

> **Technology is the know-how and the creative process that may utilize tools, resources and systems to solve problems, to enhance control over the natural and man-made environment in an endeavour to improve the human condition.**

The fact that technology is associated with those who do manual work, whereas the education system is largely controlled by those who do not, has tended to give technology a lower status in education than science. Yet it is arguable that mankind can progress without science and, indeed, has done so for millions of years. Our progress has been measured by our technological achievements. 'How do we make it work?' and 'What do we do to make it work better?' are at least as important questions for the majority as 'How does it work?'. Almost every household in the developed countries has a television set; even a child knows how to operate it, but only a few people know how it works.

Education at every stage has dual functions: it is a preparation for further studies and a preparation for future life and work. Traditionally, education systems have drawn a distinction between the two, associating science education with the former and technology education with the latter. The reasons for this separation are complex, requiring for their elucidation a detailed historical analysis of the establishment of parallel academic and technical/vocational provisions in Europe and in former colonies. Such considerations lie outside the scope of this chapter. What can be said is that if we look more deeply into the two areas of science education and technology education we discover that each is but a facet of the other, and that their separation has had undesirable effects, not simply on the quality of education as a whole, but also on the extent of opportunities available for the development of every child.

## The need for technology education

### *Needs for national development*

The importance of technological capability has been emphasized by a former Deputy Director-General of Unesco writing about education and productive work in India (Adiseshiah, 1979, pp. 139–40):

> The first problem that we face in making the curriculum functional to our life and living is that in life we are required to know how to grow paddy, how to breed and rear our cattle, how to produce milk and milk products, how to catch and market fish, how to weave cloth, how to fabricate machines or to repair a non-functioning pump-set. Unfortunately life does not present iself as physics or chemistry, economics or sociology, literature or logic but that is all that we learn at school and college.

Developing this line of argument, the case for the introduction of technology education into the framework of general education was stated in the Final Report of the International Congress on Science and Technology Education and National Development, held in Paris in 1981 (Unesco, 1981, p. 23):

> Technology, as a means to extend man's biological capabilities, is universal. Hence technology education is a *sine qua non*, both to understand the scientific basis of techniques and devices, and also to acquire the requisite skills for productive work and efficient living in different societies. Not only should all persons be equipped with a measure of scientific and technological literacy for meaningful life in a continually evolving society, but the non-technologists, engaged in policy- and decision-making at different levels need to be inducted to technology to ensure more effective functioning, whether as legislators, administrators or planners.

Technology education, therefore, deals with the technology that pervades all our lives and which determines, whether we are aware of it or not, the quality of life and the possibilities for increasing our chances of survival. It deals with our needs and the artefacts and techniques that are developed to satisfy them.

Consider the motor-car. Not all of us, even in economically advanced societies, can afford to own a car. Nevertheless, the existence of motorized vehicles affects all our lives. It is for this reason that every child should be taught about the automobile: how it works, its uses and abuses, and its effects, good and bad, on our lives and on our environment. A farmer in a remote region may learn to live without one, until his land is hit by drought. Then the availability of such transport could determine his fate and that of his family.

However, room for such a topic is seldom found in the secondary-school syllabus, though it may have been covered in one or two lessons by a conscientious teacher at primary-school level. It is not unusual for physics graduates to be unaware of the dangers involved in charging a car battery, or of the role of the carburettor in the determination of the performance of the engine. Surely these topics should be dealt with very early in secondary-school education. What technology education needs is room in the syllabus, in the curriculum and in the education structure.

Many governments recognize this need, but the introduction of a technological component into the general education system is often impeded by the system itself. Technology is only taught within the context of vocational training. Science, as distinct from technology, is reserved for the academic group. It cannot be denied that the needs of development and industrial progress include a supply of managerial as well as technical manpower. But it is a serious mistake to separate children, at an early age, into parallel and immiscible streams that lead inexorably to predetermined categories of employment.

## *The needs of the school-leaver*

The provision of secondary-school education in Third World countries often poses a dilemma. Should it be free and compulsory for all or should it involve fee payments with voluntary attendance? Usually it is the latter, resulting in a high level of post-primary drop-out among children who are at an age at which it is illegal to employ them. Because of the social problem of delinquency which this unemployment creates, the education authorities in some countries have now decided to adopt a different policy. They encourage children to proceed to secondary school by reducing the fees and by making the entrance examinations easier. This has the obvious disadvantages of increasing national expenditure on education and of admitting to secondary school children who may be unable to benefit. The burden of coping with the latter problem falls on the already overburdened teacher.

The advantages are less obvious because they are only apparent in the long term. It is anticipated that the child's tendency towards delinquency will decrease in proportion to the length of the period of schooling, with resultant savings to the taxpayer. Furthermore, the street-urchin problem is reduced. Those children who, for financial reasons, have to leave school, will find less competition for casual jobs and will not have to turn to crime to make a living. A third benefit is that the quality of school-leavers who enter the job market will be improved even in the case of children who have not been particularly successful in their studies. The job-seeker is easier to train if the period of education has been extended.

To these considerations must be added others about the quality of the secondary education experienced by children. As far back as 1971 it was argued that

> The traditional weakness of secondary education in developing countries has been its *wasteful role as a preparatory stage for university education*, since a large majority of students never continue to that stage. In the context of rapid technological change in the societies of the developing countries, there is an *urgent need for redesigning secondary education* as a comprehensive and terminal unit, with emphasis on a sound basic training as well as the acquisition of adaptability, with regard to skills. In particular, science, mathematics, and possibly workshop experience, must form essential elements of such education [United Nations, 1971, p. 99].

For over a decade there has been a desire to implement science education programmes which meet the needs of the populations of the various countries. This aim should be still more strongly emphasized in respect of technology education. Matching the technology education programme to the needs of each particular society should be a key aspect of the adoption of such a programme. If such educational reform is to be relevant, we must seek the active participation of the industrial sector and other appropriate institutions in the preparation of curricula and their regular up-dating.

## *The needs of women*

Technology education should not be seen as male-orientated. The acknowledgement of women's involvement with technology is essential, and aspects of the subject that are of interest to women should be included in the syllabus. Aspects of technology related to the quality of life, such as family planning, its implementation and its benefits, are of great consequence to women. Women are traditionally responsible in the home for sustaining the health, nutrition, hygiene and safety of the family. The kitchen is usually the most technically orientated and dangerous place in a home.

The presence of various chemicals in the home should be mentioned in the classroom. Reference to their use in cooking, cleaning and stain removal, and their effects on natural and synthetic fabrics, can enhance the teaching of chemistry. Many of these chemicals can be used to make soap, polishes and cosmetics. Any mother would be delighted to know that soft drinks contain mainly water, sugar, citric acid and flavouring, and that she can purchase all these ingredients (except, perhaps, the water) at supermarkets and pharmacies.

Access to different aspects of technology education should be available equally to girls and boys. Even in the Third World, girls are sometimes excluded from agriculture classes, though most of the farmwork and market gardening in these countries is done by women. This situation is changing, however. Many schools, both in the industrialized and in the developing world, are allowing children to decide for themselves which of the technical subjects they wish to study. To many it has come as a surprise to discover the large number of boys who choose to learn cookery and girls who opt for woodwork. It is, in fact, a trend that has been prevalent in the adult evening or hobby schools in the industrialized countries, and has grown out of a need which is seldom recognized. Many young adults and school-leavers who move to the towns live alone or in shared apartments. They have to know how to cook, to sew and to repair furniture irrespective of whether they are male or female. This non-discriminatory trend in technology education has not always been accommodated by schoolteachers, more perhaps because of time-tabling difficulties than insensitivity to the changing circumstances of school-leavers.

## Model curricula

### *The aims and objectives of technology education*

Technology education is not to be confused with vocational education. Nor is it to be equated with handicraft subjects such as cookery, woodwork, metalwork and dressmaking, which are a feature of most schools. At the Unesco International Symposium on the Teaching of Technology within the Context of General Education in 1985, there was general agreement on the following points (Unesco, 1985, p. 10):

> Technology education should be conceived in relation to its contribution to the educational process as a whole (education through technology).
>
> Technology education should be relevant to the local environment, the world of work, individual and community needs in daily life, as well as development of positive attitudes towards manual work and skills.
>
> In teaching technology, the interaction of science and technology should be clearly emphasized and brought out.

The development of skills related to decision-making, problem-solving, design and fabrication should form an integral part of technology education.

The objectives may be summarized as follows:

To develop mental and manual skills in the design, fabrication and objective evaluation of familiar, unfamiliar and new artefacts.

To promote the development of curiosity, inquiry, initiative, ingenuity, resourcefulness and discrimination with respect to all facets of the environment and, in particular, to the local technology.

To foster attitudes of co-operation and social responsibility.

### *The science and technology syllabus*

Within the framework of the above aims and objectives it is possible to devise a technology-oriented science syllabus, which considers a broad spectrum of social and individual needs. The syllabus is not compartmentalized into physics, chemistry and biology. It has already been pointed out that these terms are of little relevance to the school-leaver in the world outside the laboratory.

The study of the impact of science and technology on social needs and activities includes, for example, the distribution of occupations and the need to make science education relevant to the rural population in an agrarian society as well as to the business community in a highly industrialized society; the need to demonstrate the relevance of science and technology to improvement of the quality of life within the family and the community; and the need to recognize that in many societies leisure activities for young and old, and the associated technologies, may play an important role in the healthy development of social attitudes. With considerations like these in mind, a syllabus such as the following may be devised.

## Science and technology in the economy

*Agriculture*: of relevance to agricultural workers, urban gardeners and farmers with smallholdings. Concepts from biology and ecology are developed.

*Business*: of interest to those in managerial and clerical positions. Concepts from computer science and informatics with relevance to company organization, finance and personnel.

*Energy uses*: the impact on our technological environment. Concepts from physics and economics relating to energy in its derivation from traditional, fossil and renewable sources, and in all its forms and applications, are developed.

## Science and technology in industry

*Processing*: of relevance to workers in the mining, chemical, brewing and food processing industries. Concepts from chemistry, microbiology and geology are included.

*Fabrication*: of relevance to workers in the building, construction, clothing and manufacturing industries. Concepts from physics and design, in relation to the properties and uses of materials, would be developed.

### Science and technology for living

*The home*: science and technology in the kitchen; plumbing; electrical appliances. Concepts from chemistry, biology and physics relating to nutrition, hygiene and safety are included.

*The community*: the impact of science and technology on our social environment. Concepts from biology and demography relevant to nutrition, health, sanitation and family planning would be examined. Aspects of state welfare, job-seeking and job interviews could also be included.

### Science and technology for leisure

*Entertainment*: the impact of science and technology on music, drama, the cinema and the mass media. Concepts from biology and physics could be considered.

*Hobbies*: the impact of science and technology on arts and crafts, do-it-yourself activities, sport and human physical attainment. Concepts from design are included.

Not all these areas need be covered. Only those aspects that are relevant in the local context should be incorporated into a national syllabus. For example, science and technology in business may not be an appropriate subject of study in an agrarian economy in which 80 per cent of the population live in the rural areas. Similarly, in an industrial economy in which the high level of mechanization of farming has reduced the demand for farm workers, the study of science and technology in agriculture may need reinterpretation as a leisure interest of the urban gardener.

### *The case-study*

The immediate problem created by the wide range of social interests and requirements reflected in the syllabus is that the content appears to be overwhelming. This would indeed be the case if the syllabus were to be taught in the conventional way. Ideally, a case-study method of teaching should be adopted and emphasis should be given to aspects of technology that pupils will encounter in real life, outside the school laboratory.

A case-study deals with a topic or a project which relates to an aspect of technology that affects, or has some bearing on, the lives and experiences of a significant section of the population. The everyday world should be the laboratory. To answer the question of how the case-study approach works in practice, we shall take the example of the charcoal brazier.

This is a form of heating which is used extensively in Africa, especially in southern Africa where the winter nights can be very cold. The topic is used to lead the child to an understanding of oxidation and reduction, complete and incomplete combustion, the generation of carbon monoxide and producer gas, and carbon monoxide poisoning, of which many people die through the practice of keeping the brazier burning throughout the night in an unventilated hut.

Each case-study needs to be supported by a few simple experiments which reinforce some of the concepts and highlight the scientific basis of the technology. Some case-studies will require kits to be assembled, some will require a great deal of advance planning, some will have to be based on discussion of documentary materials only, while others may involve surveys or group activities outside school hours.

Other case-studies may be constructed around practical tasks from everyday life such as maintaining a car or bicycle, constructing a compost heap, organizing an office business system, constructing a small bridge, painting a room, setting up a family budget, looking after a garden and caring for a pet. Alternatively, a technological development such as a television studio, a sewage works or a blast furnace may be the subject of a case-study (Carelse, 1985).

There should be sufficient scope within the case-study to introduce the child to important scientific concepts behind the technology and to show how science, in the context of this technology, has an effect on everyday life. As a rough guide it is felt that, if the subject of the case-study is relevant to the expected experience, interest or concern of at least 20 per cent of the population, then it is a worthwhile study. The object is to educate children for those activities which bring about change, enhance the environment, create wealth, produce food and entertainment, and generally get things done.

### Debates and discussions

The pupils themselves could choose the topic for, and organize, formal and informal debates and discussions. As many children as possible should participate so that they all learn what is involved in expressing their opinion in a variety of contexts. Every child should have an opportunity to lead a debate, where possible one of his or her own choosing. This task could take on the function of a project.

## Implementation of the syllabus

The ease with which technology education may be introduced into the school curriculum depends on many factors including the level the community has reached in technology and the degree of flexibility of its education system. The aims and objectives previously outlined in this chapter would need to be interpreted according to the specific context of each country. The strategies for implementation at the primary- and secondary-school levels might also be different and would depend on the type of local education system into which technology education was being introduced, the ability of the teachers to adapt and cope, and the training and resources available.

### Primary-school level

The curriculum should be based on the local context and related to familiar topics. Special classrooms or workshops are desirable even for work at a very basic level. Such a workshop might take the form of a project room where models could be assembled either by the teacher or by the class. The fabrication of such models could be undertaken within the manual skills or handicrafts programme already existing in schools in certain countries. When completed, these models should be retained and used for demonstration purposes in subsequent years. In this way, a supply of resource materials could be built up by the school itself. There should be an emphasis on projects which involve children in making objects or performing tasks of direct benefit to the school. Helpful ideas are contained in the *Manual for the Promotion of Scientific and Technological Activities for Young People* (Unesco, 1984). For example, projects might involve planting trees or laying out the school garden, constructing a slide projector, and fitting out a school laboratory. Activities could include participation in science and technology clubs, fairs, competitions, camps and excursions as well as soliciting assistance for technology education from parents, business concerns and government authorities.

The training of teachers for any new primary-school subject is always important. In the case of technology education, it will be essential to provide adequate training for student teachers by introducing technology subjects into the curriculum of teacher-training colleges, to provide refresher courses for serving teachers and to keep teachers informed of all technological innovations. Resource materials, including charts and monographs on specific topics and case-studies, need to be provided. Teachers' journals should regularly contain articles of technological interest.

### Secondary-school level

At the upper-secondary-school level, teachers should be specialists. Qualified science teachers should be given in-service training to prepare them for the incorporation of technology in their work. The supporting infrastructure for the implementation of technology education consists of administration, resources and a teacher-training system which is specific to the subject. In connection with administration, there should be a Ministry officer responsible for the teaching of the subject at national level. Other officers should be trained to support the change at regional level. As for resources, a national resource centre should be established to provide materials in the form of information and advice, and to produce textbooks and teachers' guides. A network for making, purchasing and distributing items of equipment should be set up if this does not already exist. Adequately equipped laboratories and workshops should be provided for all schools. Because the co-operation of teachers is essential for the implementation of a new syllabus, they need to be kept informed at all stages of the development of the curriculum and should be made to feel involved with the change. Training workshops should be run continuously in the first few years until appropriately trained specialist teachers are produced in sufficient numbers.

There are at least two types of syllabus that could be implemented at secondary-school level, a technology-orientated integrated science syllabus and a broad-based interdisciplinary syllabus to which teachers from a wide range of disciplines might contribute. The scheme outlined above, in the section entitled 'Model Curricula' on page 105, may be adapted for either of these approaches and should take account of the knowledge and skills acquired at the primary-school level.

There should be provision of equipment necessary to teach the topics and the case-studies, as well as of a set of tools that can be used by the teacher and the pupils. Workshops and laboratories are indispensible. The subject should be taught in a practical manner with the pupils developing the concepts through actual experiment.

The programme of implementation should proceed by stages as follows:

*Stage 1:* the design of the new syllabus, with teachers being involved and consulted at all stages.

*Stage 2:* the publication of the syllabus with a forum for debate set up and monitored for serious and constructive objections. A preliminary list of resource materials should be drawn up and sources for the supply of materials ensured through existing industries or through the establishment of a resource centre.

*Stage 3:* the revision of the syllabus in the light of Stage 2 and its implementation in a pilot project at a few selected, adequately equipped schools. At this stage, minor revisions of details in the syllabus should be incorporated. An examinations board should be set up and the first examination questions based on the new syllabus should be set.

*Stage 4:* the extension of the pilot project to less well endowed schools with very close and sympathetic monitoring of teacher reaction. At this stage, a comprehensive list of the resource materials should be drawn up. Sources of items which were not on the preliminary list should be sought.

*Stage 5:* the syllabus should now be implemented in all schools.

It is possible to merge Stages 3 and 4, or Stages 4 and 5, or to allow Stages 3, 4 and 5 to overlap. This reduction of the implementation time is especially advisable when the new subject supersedes an older syllabus, such as integrated science.

By this means there will be a reduction in the period of uncertainty over the examination for which the pupils should be prepared.

### *Assessment of learning*

Participants in the International Symposium on the Teaching of Technology within the Context of General Education discussed learning outcomes (skills) which at the end of a course of technology education, should be assessed, bearing the following points in mind (Unesco, 1985, p. 26):

The child's knowledge of the scientific concepts embodying the technological objects and processes included in the syllabus.

The child's appreciation and perception of both positive and negative impacts caused by the introduction of new technologies into his environment.

The child's ability to formulate and solve technological problems in his environment.

The child's design and creative skills linked to technological innovation.

The child's investigative, communicative and manipulative skills in relation to science and technology.

Formal examination of these should consist of one or two theory papers, one practical paper and a coursework project. However, apart from other difficulties, the organization of practical examinations requires a well-established infrastructure for the gathering and distribution of examination materials. Many countries may not have such facilities and may prefer an alternative paper restricted to the assessment of candidates' abilities in data interpretation, manipulation and presentation. However, it is important that manual and observational abilities should also be assessed, perhaps by coursework. Having identified the aims of assessment, a set of three to six questions can then be drawn up. These should be designed so as to require only materials that are unsophisticated, inexpensive and easily obtainable. The relationship between abilities tested by such questions and those assessed by the coursework project is also a matter to which the examiners need to give careful attention.

## References

ADISESHIAH, M.S. 1979. Education and Productive Work in India. In: Z. Morsy (ed.), *Learning and Working*, pp. 137–48. Paris, Unesco.

CARELSE, X.F. 1985. *Towards a Technology-based Science Syllabus. The New Zimbabwe O-Level Science Syllabus; Country Report* (Paper prepared for the International Symposium on the Teaching of Technology within the Context of General Education, Paris, 1985.) Paris, Unesco. (Unesco doc. ED–85/Conf. 809/COL. 12.)

UNITED NATIONS. 1971. *World Plan of Action for the Application of Science and Technology to Development*. New York, United Nations. (Sales No. E.71.11.A.18.)

UNESCO. 1981. *Final Report. International Congress on Science and Technology Education and National Development, Paris, 1981*. Paris, Unesco. (Unesco doc. ED–81/Conf. 401/COL. 10.)

——. 1984. *Manual for the Promotion of Scientific and Technological Activities for Young People*. Santiago, Chile, Unesco Regional Office for Education in Latin America and the Caribbean (OREALC).

——. 1985. *Final Report. International Symposium on the Teaching of Technology within the Context of General Education, Paris, 1985*. Paris, Unesco. (Unesco doc. ED–85/Conf. 809/COL. 21.)

# Integrating the natural sciences and other school subjects

D. Lazarov and E. Golovinsky

An integrated approach to learning is an important contemporary educational development which reflects the way that the natural sciences and other forms of knowledge interrelate in real-life industrial contexts. It helps students to develop comprehensive and general ideas about the world. The approach pervades all aspects of educational activity—the prescribing of educational objectives, the development of curricula and study plans, the organization of teaching and learning, including the choice of pedagogical strategies, and the planning of out-of-school activities.

This chapter is based on experience in the use of an integrated approach in education acquired by the Research Group on Education at the Ministry of Public Education and the Bulgarian Academy of Sciences in the People's Republic of Bulgaria. For the past eight years, thirty Bulgarian schools have been carrying out an experiment in integration under the guidance of members of this group. This has involved attempts to interrelate school subjects by developing and testing new curricula and methods of teaching (Penkov and Sendov, 1985).

A prime requirement for the successful application of the integrated approach is a clear recognition of the aims of education. Foremost among these is the development of mature and resourceful individuals who have acquired knowledge and skills that will enable them to lead useful professional lives. The need is for well-adjusted personalities, both informed and accomplished, whose attitudes to life are positive.

The achievement of such aims requires appropriate curricular planning within the overall framework of general education and vocational training. In Bulgaria the education system consists of three stages; primary and junior-high-school education, secondary education and vocational training.

General educational activities take place with children at three levels: 6 to 9 years in Grades 1 to 4; 10 to 12 years in Grades 5 to 7; and 13 to 16 years in Grades 8 to 11. There are two grades beyond this which are concerned with vocational training. The curriculum at each of the three general education levels covers a similar range of subject matter, there being gradual progression in the students' learning of this, according to their stage of cognitive development.

In primary school the curriculum is organized in terms of six areas of knowledge and experience. From the pupil's perspective these are:

1. I read; I write; I count; I read books.
2. I sing and act; I go to concerts; I paint and compose.
3. I make models and designs.
4. I learn the Russian language.
5. I take part in sports and recreational activities.
6. I become acquainted with my home country; I make friends with Soviet children; I strive for peace and the preservation of the environment.

The integrated approach is embodied in the way in which children process and synthesize information from these areas of knowledge and experience. Understanding of the natural sciences is acquired inseparably from that of history and Bulgarian language and literature.

In junior high school the number of school subjects is greater. Basic knowledge of the contemporary physical world, including the phenomena and processes which characterize it, as well as the laws and theories which govern and explain it, provides the content of an integrated subject called 'nature'. An understanding of history, and of the basic spiritual, intellectual and material achievements of mankind, is acquired by means of a second integrated course on society. An experiment has been conducted in the combined study of general linguistics and mathematics in relation to communication between people, the subject being called language and mathematics. Practical skills and knowledge relevant to the world of work are learnt in the subject life skills and industry. Particular attention is being given to the ability of students to work with computers and to this end a special Information Technology course has been introduced. Other components of the curriculum include art, music, English, Russian and sports, each of which is studied as an independent subject.

At the junior-high-school level, therefore, natural science is studied predominantly and integrally. Additionally, certain aspects of science are learnt in social studies while relevant practical knowledge may be acquired from life skills and industry, English and Russian. The junior high school represents a transitional stage in the learning of science, however. There is a gradual move away from the single integrated general subject such as nature study found in primary schools towards a more specialized teaching of science subjects which finds its full development in separate science courses in secondary schools. Some of the problems arising from attempts to integrate science in the junior-high-school curriculum deserve further attention (Golovinsky and Lazarov, 1985).

A characteristic negative feature of the teaching of natural science subjects in junior high schools, as well as in secondary schools, has been the independent treatment of each separate subject. The phenomenon of curriculum discrepancy is often observed, a typical example being the learning by students in biology lessons about heredity and its molecular basis before they have studied in chemistry lessons the structure and properties of organic substances. The extent of curriculum discrepancy varies; the interdisciplinary relations between chemistry and physics, geology and geography, and biology and geology are often good. On the other hand, the interrelations between biology and physics and biology and chemistry are weak, incomplete and unsatisfactory.

One attempt to overcome this lack of chronological co-ordination in the study of natural sciences in schools involves the strengthening of the interdisciplinary relations in the process of teaching. An important requirement here is the review of curricula and syllabuses over the whole period of compulsory education from the first to the final year. Special attention should be given to the identification of all possible interdisciplinary relations and the avoidance of any discrepancies and inconsistencies concerning the timing and placing of topics in the syllabuses.

There are many reasons for the lack of proper, consistent interdisciplinary relations in the teaching of natural science subjects in schools. While it is not the purpose of this chapter to analyse them or to offer detailed recommendations for their avoidance, we consider one reason to be of particular importance. It relates to the established traditions and practices in universities for the education and training of those who are to become science educators. It concerns not only those who teach science in school classrooms and laboratories, but also those who plan curricula and syllabuses, those who write school science textbooks and even those who supervise and direct the education system. The point at issue is the nature and extent of deficiencies in their university education. It is difficult to explain, for example, why in many countries chemists and physicists graduate from universities without ever having studied biology. Similarly, the knowledge that geographers have of chemistry and physics is often poor, and physicists may know little chemistry, if any. Thus teachers, though expert in their particular discipline, do not acquire from their university education that wider, more all-embracing perspective on science which would enable them to establish practical interdisciplinary relations in a comprehensive and systematic way in school science education.

The curricula and syllabuses in teacher-training courses in universities and higher educational institutions should be reviewed with this point in mind. We think that future chemistry teachers need to have studied at university, in addition to chemistry, biology and biochemistry (without which it is impossible to acquire knowledge of biotechnology), as well as geology and physical geography. Furthermore, these biology, geology and geography courses intended for chemistry students should be structured in such a way as to have immediate relevance to their future teaching practice. Similar considerations apply to students of natural science disciplines other than chemistry.

In a attempt to overcome some of the shortcomings of the independent teaching of science subjects in schools, a number of experiments have been carried out. As mentioned earlier, the authors had an opportuniy to share the experience of the Research Group on Education at the Ministry of Public Education and the Bulgarian Academy of Sciences, concerning the integrated teaching of nature in the higher junior course of secondary school. The experiments in question are still incomplete and the practices involved have not yet been incorporated into education regulations.

Two possibilities, at least, appear to present themselves to a science teacher wishing to improve the integration of science in the secondary-school curriculum. The first is to extend the integrated teaching of natural science, or alternatively a combination of two or more science disciplines (e.g. chemistry and physics; geology and geography), to older students. Such a course of action has been followed in several countries. The second possibility is to teach a minimum number of science subjects, sufficient to provide the necessary knowledge for young people today, and to concentrate on the development of fundamental points of integration between them. Thus biology, chemistry, geography and physics will appear in the curriculum as separate school subjects, but in their teaching every opportunity will be taken to establish interrelations.

A third possibility exists, however, which involves the application of the integrated teaching approach to the organization of the educational process. This is an extremely large field in which a number of more limited aspects can be identified.

Let us start with school textbooks. In the primary school there is one principal textbook for all subjects, a primer covering the material for one school year. Through this book a complete integration of the sciences is achieved. For example, the idea of the variety of species and biological evolution pervades an account of the work of Charles Darwin. This includes passages from his writings, with commentary, and a biographical essay, *The Wise Man of Down*, by the Bulgarian author H. Jovchev. Elsewhere in the primer the same idea is illustrated by a passage from Arthur C. Clarke's *2001: A Space Odyssey*. The subsequent lesson gives a general idea of biological species and the evolution of new species. Quite naturally the pupils move on to extracts from books such as *Doctor Dolittle* by Hugh Lofting and *The Two Monsters* by Stanislaw Lem. Their interest is further aroused by D. Jhotev's poem, 'A Bat', and by passages from the *The Kon-Tiki Expedition* by Thor Heyerdahl. The integrated theme finishes with a lesson on heredity and acquired characteristics. The book is rich in illustrations. Many animal species are mentioned, including representatives of the same and related species. The transmission of hereditary characteristics in animals, plants and human beings, through a number of generations, is illustrated. Portraits are used to show the hereditary characteristics of members of the Emperor Maximilian's family. The text includes a number of questions for individual work by pupils and there is an illustrated glossary of new words and concepts. Often information is imparted in Russian and is incorporated in assignments for pupils.

This example indicates the variety of ways in which an understanding of the origin and variety of species might be acquired. At the same time pupils become acquainted with the interpretation of this idea in literature and art, as well as with its importance and significance in human affairs. An attempt is made to connect reality and science on the one hand and fantasy and imagination on the other. In this way there is a favourable combination of the acquisition of concrete information and knowledge with the development of individual concepts and imagination, facts being assimilated as a creative process is taking place in the child's thinking.

The same kind of approach can also be found in books used in the higher grades of the junior secondary-school course. In this case, however, there are separate textbooks for each school subject. For pupils showing a particular interest in several subjects, there is optional interdisciplinary material, for example in Russian and English. The children also have a reader, containing extracts from all fields of human knowledge, and an encyclopedia, containing new and unfamiliar words and concepts.

The textbook for natural science contains separate integration sections. Each lesson has a summary in Russian and English which is studied in language lessons, thereby fostering an interest and skill in the use of precise, correct nomenclature. Here again, illustrations and figures play a considerable part in the development of understanding. Some of the assignments demand editorial abilities in relation to both scientific and stylistic considerations. For example, one task for individual work by pupils involves a passage of text which is to be edited. This is in fact the bridge to language learning and mathematics. By a careful formulation of his thoughts in the field of natural science, the pupil develops writing skills in his mother tongue. There are numerous assignments that have an immediate relation to everyday life and develop practical skills. Good use is made of the historical approach, thus providing an opportunity for the evaluation of achievements in terms of their particular historical contexts. The extracts in the reader, from the writings of well-known and recognized authors, supply additional information depicting realistically the author's own times. Pupils have an opportunity to read passages about science by Jules Verne, Jakov Perelman, Jack London, Mark Twain, Rudyard Kipling, Charles Darwin, Michael Crichton and many others. In this way, the relation between natural science and its representation in literature and fine arts is further strengthened. Some extracts are in foreign languages.

The use of school textbooks in the upper forms of secondary schools is being investigated by the Research Group on Education and their experiment is still being developed. Their basic idea is that the textbook at this level should be more like a thesis; that is, it should include many passages from publications in diverse fields of science and technology, together with extracts from literary works, to exemplify the cohesive relationship between different fields of human knowledge.

Another important aspect of the organization of the educational process is the actual conduct of each lesson. The traditional expository lecture by the teacher for the introduction of new information has been replaced. Instead, the lesson is organized in a way which allows individual learning of new knowledge by reading the texts, the glossaries and encyclopedias, with laboratory experiments being carried out as an independent activity. The main role of the teacher is now that of guide and assessor. In fact, the teacher tries to turn the individual pupil's question into a class discussion or debate which he must then skilfully conduct in order to achieve the desired pedagogical outcome. Work on assignments and on passages from literary works is of particular importance. For example, understanding of an extract from Michael Crichton's *The Andromeda Strain* requires some elementary knowledge of the radiographic analysis of cells, mitochondria and ribosomes, electron microscopy, television intensifiers and magnification. Fiction here leads into reality. Other texts take the pupils back into the laboratories of the past and oblige them to face the problems of our great scientific ancestors. Pupils learn about the scientific investigations of Pascal and his discovery of general laws governing the behaviour of liquids and gases from T. Boretz's book *Good Afternoon, Mr Ampère*. In this way pupils experience the intellectual ambience of the period and the gropings of the creative mind, including occasional erroneous steps.

Thus, in one lesson the theories of a particular science are studied along with their representation in, and impact on, literature, including both science fiction and works by authors who do not limit themselves to any specific scientific theme. Literature and art each deal with human emotions; at the same time, they convey much information about everyday events and processes and are a rich source of knowledge about nature. There is no need to commission special texts when there is the possibility of drawing upon the resources of the world's literature and culture in their original form.

What kind of teacher is needed to ensure the success of these innovations? The main issue is whether this teacher should be a highly qualified but narrow expert or a more general encyclopedist. As far as the primary school is concerned, and in accordance with much international practice, our preference has been for the latter. Apart from the teaching of sports and foreign languages, where qualified experts help, such teachers have proved entirely successful. In the higher-secondary-school course, the more narrow and specialized teacher has been preferred. Interestingly, as an experiment, different subject specialists have been used to teach the same school subject and the results of this innovation studied. Thus, teachers of biology, chemistry, geography and physics were all given responsibility for teaching natural science. Each was well qualified in a science subject and had a sound initial training as a teacher. Over a period of three to four years, these teachers showed considerable improvement in their scientific and pedagogical skills, sufficient to solve the educational problems they encountered in interdisciplinary work.

Several reasons can be advanced to account for the progress of these teachers. Their involvement in a novel experiment which was the subject of considerable interest no doubt played a part. The interdisciplinary teaching made demands on their creativity and innovatory skills to which they responded. Furthermore, they were made aware that teachers were not expected to know the answer to every question that pupils might ask; it was acceptable to admit ignorance, provided an attempt was made by the next lesson to repair the deficiency. Other influences included the involvement of teachers in in-service courses to improve their professional qualifications and in annual science education conferences where they discussed talks about their interdisciplinary work.

Much more could be written about the trend to integrate science teaching and the research into the relationship between different school subjects which the Research Group on Education is carrying out. The essential requirement, however, is that science is learnt by pupils from a diverse range of sources, including textbooks, but also works of literature and art, laboratory experiments and observations the environment. Science should not be seen as separable from its cultural context; it is both a product and a powerful determinant of it.

## References

GOLOVINSKY, E.; LAZAROV, D. 1985. An Experimental Programme in Integrated Natural Science Education in Bulgaria. *Prospects; Quarterly Review of Education* (Unesco), Vol. 15, No. 4, pp. 593–6.

PENKOV, B.; SENDOV, B. 1985. *The Bulgarian Academy of Sciences Research Group on Education Project.* Rev. ed. (Paper presented at the International Conference on Mathematics Education organized by the University of Chicago School Mathematics Program, Chicago, 1985.)

# *Training teachers for interdisciplinary work: the state-of-the-art, with special reference to the Caribbean*

Joyce Glasgow

The term 'interdisciplinarity' continues to be a source of academic debate. D'Hainaut (1981) distinguishes between intradiciplinarity (learning principles in a specific discipline for transfer to others), interdisciplinarity (learning general principles which can then be applied in a number of different disciplinary contexts), multidisciplinarity (drawing upon several disciplines in the study of a theme or problem) and transdisciplinarity (structuring subject matter around the cognitive and affective activities of the learner).

Hungerford and Peyton (1980), with reference to environmental education, equate multidisciplinarity with infusion, and interdisciplinarity with a conceptual unit with input from several disciplines. Moroni (1978, p. 483) defines interdisciplinarity as 'a way of organizing specialized knowledge that modifies concepts and boundaries of separate disciplines and gives them a new and original form'; while Francis (1985, p. 33), in a review of graduate-level environmental education courses, found that the term was interpreted mainly in three ways, to refer to: (a) a conceptual integration of subject matter from two or more disciplines; (b) a personal integration of one's own knowledge and experiences which are integral to one's development; and (c) a practical integration of knowledge and skills to solve various problems. Thus the word covers a wide spectrum of meanings.

In this chapter, the term will be taken to cover any modification of subject boundaries which makes them less distinct and rigid. Such modifications may run the gamut from identification of links between disciplines, through integration based on common concepts and/or principles, to the study of wide problems which require for their solution a multiplicity of skills and a wide knowledge base encompassing several disciplines. These different types of interdisciplinarity can be represented on a continuum, as illustrated in Figure 1, and are associated with different teaching approaches.

In practice they are more or less suitable for different levels of the formal education system. At the two 'ends' of the system as it normally exists worldwide, that is, at the primary and tertiary levels, it would seem that interdisciplinarity in one of its more fully developed forms can be readily accommodated. Thus, the generalist class teachers in the primary school may, if government policy allows, use the complete open school model and abolish subject boundaries entirely or, at least, employ a restricted modification such as the integration of groups of subjects. Similarly, at the opposite end of the system, at university level, as Gozzer (1982, p. 289) has pointed out, extremely sophisticated versions of integration may be achieved. For example, 'there is no longer a discipline called "history": there are countless lines of approach to history, through diachronic development, synchronic patterns, disciplinary connections.'

Although what might be called the middle ranges of interdisciplinarity are to be found throughout the education system, they appear, up to now, to have been most prevalent at the secondary-school level. This is the stage at which there seems to be greatest conflict between breadth of exposure to various disciplines and depth of understanding of any one. In terms of the teaching strategies required, this level is probably the most demanding.

All these considerations should influence the training of teachers if they are to be equipped to deal effectively with the problems of interdisciplinary teaching at

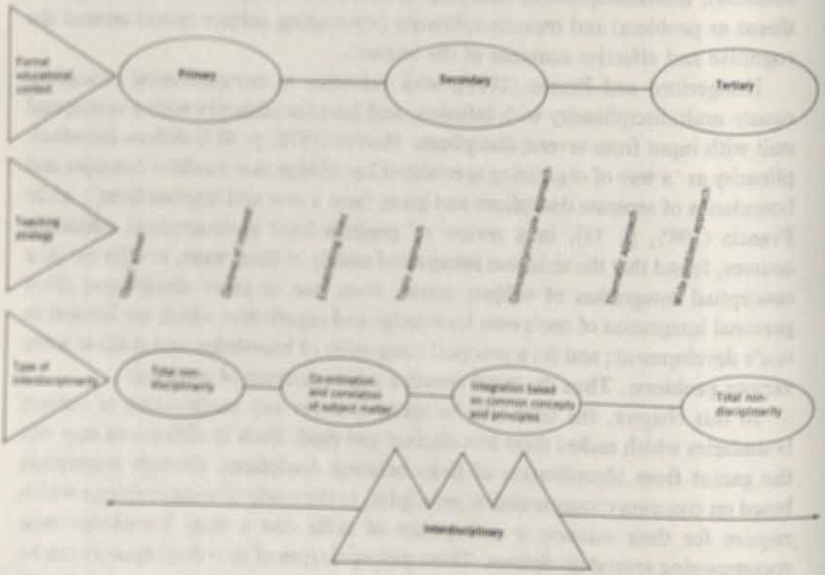

Formal educational context
Primary
Secondary
Tertiary
Teaching strategy
Type of interdisciplinarity
Total non-disciplinarity
Co-ordination and correlation of subject matter
Integration based on common concepts and principles
Total non-disciplinarity
Interdisciplinary

FIG. 1. Contexts and teaching strategies for different types of interdisciplinarity.

particular levels of the education system. Training strategies, however, appear to have resulted more from the specific teaching problems of particular fields of study than from any general analysis of what interdisciplinarity entails. Within science and science-related disciplines, examples of such fields of study include agriculture, environmental education, family life education, food and nutrition education, and integrated science. Teacher-training provisions within these fields will now be reviewed.

## Teacher training in some interdisciplinary fields of study

### *Agriculture*

This field will be illustrated by case-studies from Israel and Belize. In Israel the curriculum for the Agriculture as Environmental Science Project (Blum, 1985; see also page 155 below) established in the late 1960s, is co-ordinated with the science curricula. In-service training for teachers, special students' texts, teachers' guides and instructional materials including living specimens have all contributed to a highly successful programme which is utilized at both primary- and secondary-school levels. Titles of some of the units illustrate the topic approach to interdisciplinarity. For Grade 6: 'Seeds germinate'; 'The voice of the turtle is heard in our land'. For Grades 8 to 9: 'Fight against hunger'; 'Let's keep bees'. Lesson outlines involve biology, economics, environmental considerations, plant and animal breeding, and nutrition. In Belize, the Relevant Education for Agriculture and Production Programme (REAP), which was formerly known as Rural Agriculture and Education Programme (Eck, 1986), designed to make agriculture meaningful to the primary-school children of Belize, was started in 1977. Instead of introducing agriculture as a subject, certain related areas of study (village/urban study, land and water, ecology, weather, agricultural practices, health and nutrition, animals and plants) have been integrated into traditional academic subjects. For example, the idea of a biological life cycle is illustrated by rearing chickens, while the slaughter and sale of the chickens provide a basis for lessons on record-keeping and small-business management. In this way, agricultural technology and economics are integrated with science.

Initial training of teachers takes place on the pre-service certificate course at the Belize Teachers' College. In-service workshops are also provided. Additional support for teachers includes learning activity packs comprising detailed lesson plans and resource manuals giving technical information on the agricultural science, health and nutrition, and methodology components of the programme. These written materials were developed by project staff with help from practising teachers.

Both the Israeli and Belizean projects have had continuous political support from their respective ministries of education and, in the case of Belize, funding and technical help are still being supplied by some international agencies. These factors, coupled with continuing pre- and in-service teacher-training activities, have undoubtedly contributed to the success of these innovative approaches to interdisciplinary education.

### *Family life education*

Family life education may be thought of as including considerations of family structure (sociology), communication and interpersonal relationships, responsible parenthood (psychology), reproduction, growth and development (biology), health and nutrition, and consumer education (economics). Its concerns, therefore, cross the boundaries of several disciplines.

The Caribbean experience does not suggest that such teacher-training for family life education as provided has taken great cognizance of its interdisciplinary nature. For six years up to and including 1981, the Ministry of Education in Jamaica funded a special one-year course in guidance counselling, initially at the University of Western Carolina, but later at the University of the West Indies. The course, designed to satisfy a need which secondary schools were expressing at the time, was primarily meant for guidance counsellors, but some other teachers also benefited. Family life education was one small component of this course.

At present, through the National Family Planning Board, and with funding from the United States Agency for International Development (USAID), the ministry is running a family life education programme, this time catering definitely for all teachers throughout the system, from primary-school to training-college level, as well as for school nurses and guidance counsellors. A source book of technical information and a handbook to help teachers with teaching techniques have been developed, along with simply written literature, which children can use on their own or with their teachers.

The United Nations Fund for Population Activities (UNFPA) has also funded training for family life education throughout the Caribbean, but a recent evaluation report reveals that the family life educators trained are for the most part health personnel (UNFPA, 1984). The UNFPA projects have made contributions to teacher training through short courses, and teacher-training college curricula in the region also have various family life education components. Supporting material is, in general, scarce throughout the region (CRESALC, 1982).

### *Food and nutrition education*

In a commentary on Hornik's (1985) state-of-the-art review of nutrition education, Van der Vynckt (1985, p. 102) laments the fact that the formal and non-formal education systems, 'two of the most potent socializing agents to which individuals are exposed' were not covered in the review. This omission is especially disappointing at a time when nutrition educators are stressing the fact that the scope of nutrition education needs to be broadened, and that the role and scope of the nutrition analyst/educator/activist needs to be reconceptualized along more interdisciplinary lines. Israel and Tighe (1984) in their comprehensive review of the literature on food and nutrition education found that there is, in the field, a growing commitment to the application of skills from diverse areas of study such as anthropology, epidemiology, education, communications and the social sciences.

In the Caribbean, recent evidence of this commitment has been manifest in links forged between education and the media, and in a definite stress on the nature and credibility, or otherwise, of traditional food beliefs. Links have been established at all levels of the education system, and the strategy has largely been to try to reach children and their families through training their teachers. Much of the credit for this goes to the Caribbean Food and Nutrition Institute (CFNI), a sub-agency of the Pan American Health Organization (PAHO). In collaboration with the Faculties of Education of the University of the West Indies and the University of Guyana, along with ministries of education and health and teacher-training colleges in the region, CFNI has, over the past six years, conducted several short courses, seminars and workshops', and encouraged curriculum revision.

Infusion of food and nutrition concepts into existing curricula has been the focus of this work. One outcome has been that the learning of food and nutrition concepts no longer takes place solely within the traditionally female-dominated home economics courses; a greater stress is now being placed on these concepts in science, social studies and physical education courses.

Supporting materials have also been prepared by the teachers themselves. For example, a handbook for Caribbean primary-school teachers, prepared in Montserrat, is now being used throughout the entire English-speaking Caribbean, and currently a guide for teacher educators in the teacher-training colleges is being prepared by the collaborative effort of the University of the West Indies, selected teacher educators and CFNI (CFNI, 1985).

Except for the fact that the audiences have been different, pre- and in-service training provisions have followed a similar pattern. The focus of pre-service has been on teacher educators, and of in-service on classroom teachers.

Mention must be made of the contribution of the University of the West Indies Distance Teaching Experiment. Using these facilities, a CFNI nutrition educator, operating from the university's Mona campus over the three years 1984-86, has provided content update for primary-school teachers in areas of the region widely separated by the Caribbean Sea including Jamaica, Trinidad and Tobago, Antigua, Saint Lucia, Barbados and Dominica. The programme illustrates the possibilities for making better use of scarce human resources by way of long-range audio-visual communication.

Three aspects of the work of CFNI augur well for the success of its efforts. First, there are planned follow-up and evaluation exercises for the workshops. Second, reference material on research findings and on indigenous foods and traditional food beliefs of direct relevance to the region, is produced on an on-going basis. Examples are the journal *Cajanus*, and the less sophisticated *Nyam News*. (*Nyam* is a Jamaican dialect term meaning 'to eat'). Third, the Institute is broadly based and works with community personnel and a wide range of other agencies—agricultural, medical, health, research and media, as well as educational—in promoting improved nutritional behaviour. Thus its work is truly interdisciplinary in context; although not all its output is directed to teachers in the classroom, in so far as it has an effect on society in general, there will be feedback which will influence what teachers do.

## *Integrated science*

Fensham (1979, p. 84) notes that the word 'integration', however it is used, implies a bringing together. Haggis and Adey (1979), in their review of integrated science courses worldwide, based their selection of courses on Blum's scope and intensity model, 'scope' signifying the range of disciplines covered and 'intensity' the extent of the blending of subjects. On this definition, only those courses with at least two disciplines, fairly closely interwoven, were included. The same definition is adopted here: further, the term is here confined to the more academic school disciplines i.e. biology, chemistry, physics and earth science.

The proliferation of integrated science school curricula in the 1970s generated new teacher-training curricula 'after the event', though ideally teacher training should precede implementation. The problems posed in designing training courses for teachers of integrated science are similar to those encountered in the training of single-discipline science teachers, but they are intensified.

Teacher trainees for the primary-school level usually have a weak science background which engenders lack of confidence. This, in turn, encourages them to shy away from science teaching whenever possible. Secondary-school student teachers, in contrast, find it difficult to make the adjustment from the single discipline into which they have been previously initiated. Group learning, self-instructional packages and special introductory courses have been strategies used to make good the deficiencies in students' scientific knowledge.

Van der Cingel (1979, p. 88) has pointed out, however, that in addition to this requirement for understanding concepts from a range of sciences, teachers of integrated science need to experience problems similar to those of their pupils, for example, problems involving decision-making. They also need to develop an attitude that allows them to look beyond discipline boundaries and to support this with a teaching style that facilitates both co-operation between pupils and interdisciplinary activities with colleagues. Noteworthy, too, is the opinion, expressed at the Nijmegen conference in 1978, that converting single-subject specialists is difficult and, in the long run, an inadequate method of supplying integrated science teachers.

The above observations can all be exemplified from the Caribbean experience. The region was well represented in the generation of integrated science curricula in the early 1970s (for example, West Indies Science Curriculum Innovation Projects A and B in Trinidad and Tobago, C in the eastern Caribbean, and the Mona project in Jamaica). The innovations were directed at the lower secondary school. It is perhaps not surprising, then, that one of the earlier international conferences on the teaching of integrated science was hosted in Barbados. The report of this 1973 conference (Reay, 1974) became a bench-mark in the evolution of integrated science teaching.

This conference influenced the conceptualization of the University of the West Indies (UWI)/United Nations Development Programme (UNDP)/Unesco/United Nations Children's Fund (UNICEF) Teacher Education Project RLA 142, which adopted an integrated approach to science teaching. RLA 142 was a wide-ranging teacher-education project which spanned the entire Caribbean; it trained teacher educators as well as pre- and in-service teachers. An important output of the project was the workshop production of a series of top-quality self-instructional, self-evaluative, integrated science teacher-training manuals on such topics as energy, chemical change and ecology. Each unit in a manual relates three levels of instruction, that of the teacher educator, the teacher trainee and the pupil. In this way the method of instruction of teacher trainees is related to the tasks they will perform at school. The participation of teacher educators increased their own level of skills, and the materials continue to serve as a useful resource for subsequent teacher educators and classroom teachers.

Several participants at this conference also helped to develop the integrated science (double award) syllabus offered by the Caribbean Examinations Council at the upper-secondary level. This innovation, which in 1979 began so hopefully, has been considerably hampered in its implementation by teachers' resistance largely born of inadequate teacher training. Its fate exemplifies the Nijmegen observation that retraining single-subject science specialists to teach integrated science is difficult.

Newer Caribbean Examinations Council syllabuses continue to influence teacher training in the region. For example, in Jamaica in 1981 the science syllabuses designed for the new three-year diploma college programmes introduced in that year were considerably influenced by the expected introduction of the Caribbean Examinations Council integrated science (single award) syllabus in 1983.

A thematic approach, spanning the biology, chemistry, physics and earth science disciplines, was used with those trainee teachers expected to teach only this syllabus at secondary-school level. Those likely to teach integrated science and/or biology, chemistry and physics as single sciences were required to cover more detailed content in all three science subjects. It is, however, hoped that the methodology courses will help students to integrate the sciences in their own minds. Additionally, the syllabuses have been designed to promote, as far as possible, an interdisciplinary approach to some concepts, for example, energy. As yet it is too early to evaluate the effectiveness of these strategies, but it is worthy of note that this is the first time that a deliberate acknowledgement has been made of the needs of the teachers of integrated science in designing these courses.

At the undergraduate level in the University of the West Indies, in-service certificate courses are designed to upgrade the competence of college-trained teachers in the teaching of integrated science. In the post-graduate diploma programme, however, single disciplines are again the focus, though some attempt is made to include lower school integrated science teaching.

Alabi (1978), reporting from Nigeria, describes an alternative strategy to facilitate the introduction of integrated science into junior secondary schools. Student teachers offering double science combinations, for example biology and chemistry, were required to take also an integrated science course which covered both content and methodology.

## Environmental education

Environmental education is considered subsequent to other curriculum areas, because it encompasses aspects of them all. The environment as a basis for interdisciplinarity is, perhaps, unsurpassed in the scope of its application. This is illustrated in Figures 2 and 3 which represent diagrammatically areas of overlap of science and technical/vocational education with environmental education.

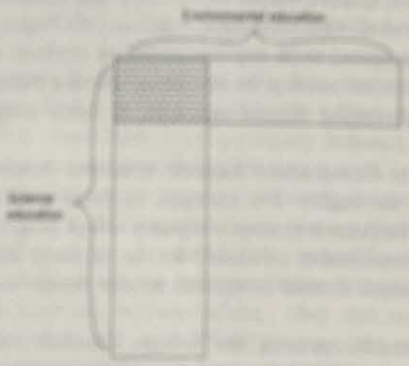
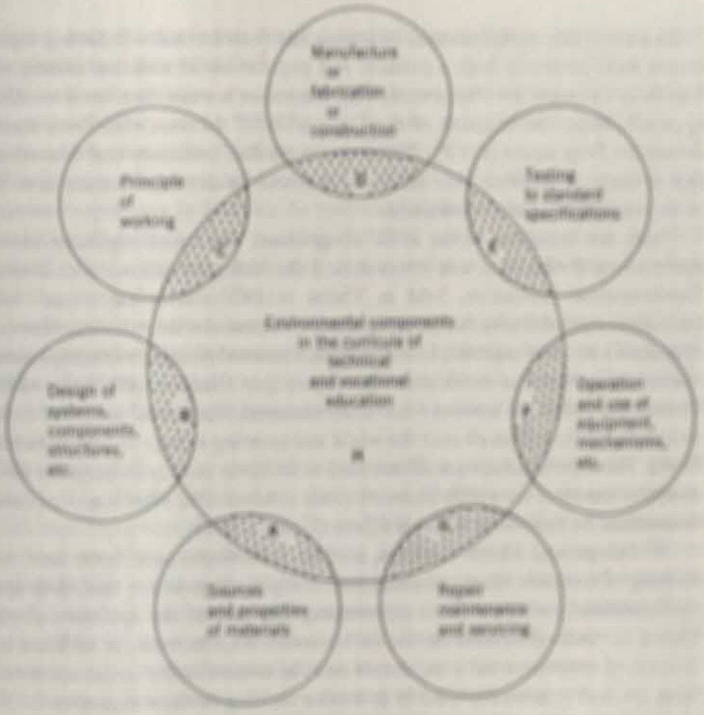


FIG. 2. An overlap model for the way science education contributes to environmental education (After Jacobson, 1986, p. 17).



A. Sources of energy (non-renewable)
Properties of materials, land, air, water, etc.
Properties of chemicals and materials which cause pollution

B. Design aspects pertaining to sanitation, safety, waste and refuse disposal, exhaust gases, etc.

C. Use of non-renewable energy sources.
Nature of exhaust gases; efficiency

D. Processes focusing on lessening waste and minimizing pollution, treatment of waste and effluents, etc.

E. National and international standards and techniques for testing air, water, food, noise, etc.

F. Operational procedures and their relationship to ecological factors.

G. Repair, maintenance and servicing of equipment used for monitoring and controlling pollution.

H. Research and development to produce new processes and techniques with an accent on environment.
Problems and projects from industry

FIG. 3. Environmental areas in the curricula of technical and vocational education (After Unesco, 1986, p. 25).

In a sense too, environmental education has been fortunate in having captured almost simultaneously both a political and popular world audience arising out of humanity's concern for its survival. This has meant a more structured world-level approach under the auspices of the Unesco/UNEP International Environmental Education Programme (IEEP). This is not to say that environmental education is a new concept, but rather that efforts to promote its development are now being more emphasized and co-ordinated.

From the inception of the IEEP programme, the interdisciplinary nature of environmental education was stressed, and the Intergovernmental Conference on Environmental Education, held in Tbilisi in 1977 clearly enunciated teacher training as a priority area for the programme. To promote this training, Unesco has organized a series of regional, subregional and national training workshops aimed at teacher educators and curriculum developers (see Glasgow, 1983). In addition, Unesco has published a series (the 'Environmental Education' series) of modules written by authors from all over the world and covering a range of topics (Jacobson, 1986). These publications are all intended to facilitate teacher training. In the final analysis, however, even with Unesco's active intervention, what is accomplished is determined by individual country efforts (Unesco, 1983).

In Europe and North America, various procedures have been used in the training of teachers, often including interdisciplinary practices related to specific environmental problems (thus representing one end of the spectrum shown in Figure 1). General courses on the environment are also used, in addition to the infusion of environmental components into the natural and/or social sciences. The latter method is generally used in in-service training in these countries.

In other regions of the world, including Africa, Asia and the Pacific, the Arab states, Latin America and the Caribbean, infusion is the generally adopted strategy for both pre- and in-service teacher training. Many countries in Asia and the Pacific have instituted general environmental courses into their programmes.

In Africa, in-service training tends to be sporadic and often restricted to occasional lectures dealing with health or conservation problems, while short courses addressing urgent environmental problems are the main in-service vehicle in the Arab States and Latin America and the Caribbean. A further improvement in the latter region is the use of interdisciplinary practices for retraining rural teachers.

## Conclusion

The fact that this volume has devoted an entire section to considerations of interdisciplinarity testifies to the increasing concern that there should be what Souchon (1985, p. 540) terms an 'opening to the outside world' of science education, in order that it may better assist children to face the problems of their future individual and social lives.

The institutionalization of an interdisciplinary component in teacher training is a necessary corollary of this opening up. In sum, the points emerging from the present review of work in this field are as follows:

1. The infusion strategy is most often used, reflecting the difficulty which science teachers experience in deciding the optimum balance between interdisciplinarity and disciplinarity in their teaching. Infusion offers a compromise approach which permits the introduction of new material without unduly disturbing existing curriculum structures.
2. Most success has been achieved in those subject areas which have a direct effect on man's well-being, for example, agriculture (for food), nutrition (for health) and environmental education (for the survival of his life-support system). The problems associated with these areas can only be solved by an interdisciplinary approach.
3. The study of the more academic sciences still does not influence the general populace as it should, perhaps because of irrelevance in its presentation. Although integrated science has been widely acknowledged as an appropriate form of school science, teacher training for the most part makes insufficient provision for teachers to become competent in it. Graduates of university courses such as environmental management, engineering in its various forms and industrial chemistry, which are truly interdisciplinary in nature, rarely enter the science-teaching profession.
4. Political support is essential for the success of any attempts to introduce interdisciplinarity into teacher training, as well as into other parts of the education system. The success of the Israeli Agriculture as Environmental Science curriculum, the Belizean Relevant Education for Agriculture and Production programme and activities are but a few of the many examples that attest to this.
5. World co-operation is invaluable. International agencies and science associations play an extremely important role. Not only do they provide funding and technical expertise, but their activities promote cross-cultural sharing of ideas, and their publications are a valuable source of information.

Malitza (1982) predicts that, in the future, the teaching of science will be carried out in a more 'contextual' way with an emphasis on the practical problems solved by science; that it will include elements of 'science ethics' and 'technology assessment', incorporating a value-orientated approach; and that it will explore 'border areas'. If his ideas are correct, and the indications are that the progress of science and technology will necessitate changes in these directions, then although much has been done to come to grips with the problems of interdisciplinarity, much remains to be done. The teacher will remain a central figure in this work, and therein lies the challenge for teacher education.

## References

ALABI, R. 1978. Training Teachers for School Science in Nigeria. *Prospects; Quarterly Review of Education* (Unesco), Vol. 8, No. 1, pp. 105–9.

BLUM, A. 1985. Agriculture and Environmental Education. (Paper presented at a Conference on Science and Technology Education and Future Human Needs, Bangalore, India, August 1985. The Committee on the Teaching of Science of the International Council of Scientific Unions in association with COSTED, ICASE and Unesco.)

CFNI (CARIBBEAN FOOD AND NUTRITION INSTITUTE). 1985. *Report (Final). Nutrition Education Workshop, Ministry of Education, Guyana*. Georgetown, Guyana, Caribbean Food and Nutrition Institute, Pan American Health Organization. (Mimeo.)

CRESALC (UNESCO REGIONAL CENTRE FOR HIGHER EDUCATION IN LATIN AMERICA AND THE CARIBBEAN). 1982. *Designing Family Life Education Publications for Schools in the Caribbean*. (Report of the first CRESALC Workshop in Family Life Education for the Caribbean.)

D'HAINAUT, L. 1981. Interdisciplinarity and Integration. In: L. D'Hainaut (ed.), *Curricula and Lifelong Education*, pp. 201–29. Paris, Unesco.

ECK, D. 1986. Education for Agriculture and Production. (Paper presentend at the Consultation on Science Education Research in Latin America and the Caribbean. Trinidad, University of the West Indies.)

FENSHAM, P. 1979. Strategies and Implementation of Integrated Science Education at the Post-Secondary Level. In: J. Reay (ed.), *New Trends in Integrated Science Teaching*. Vol. 5, pp. 77–84. Paris, Unesco. (The Teaching of Basic Sciences.)

FRANCIS, G. 1985. Perspectives on Graduate Level Environmental Management Courses. *Environments*, Vol. 78, No. 3, pp. 29–41.

GLASGOW, J. (ed.). 1983. *Sub-Regional Workshop on Teacher Training in Environmental Education for the Caribbean. Final Report*. Jamaica, University of the West Indies.

GOZZER, G. 1982. Interdisciplinarity. A Concept still Unclear. *Prospects, Quarterly Review of Education* (Unesco), Vol. 12, No. 3, pp. 281–92.

HAGGIS, S.; ADEY, P. 1979. A Review of Integrated Science Education Worldwide. In: J. Reay (ed.), *New Trends in Integrated Science Teaching*. Vol. 5, pp. 35–9. Paris, Unesco. (The Teaching of Basic Sciences.)

HORNIK, R.C. 1985. *Nutrition Education: A State-of-the-Art Review*. New York, United Nations. (Nutrition Policy Discussion Paper No. 1, Administrative Committee on Coordination: Subcommittee on Nutrition State-of-the-Art Series.)

HUNGERFORD, H.R.; PEYTON, R.B. 1980. *Strategies for Developing an Environmental Education Curriculum*. Paris, Unesco. (Unesco doc. ED-80/WS/134.)

INTERGOVERNMENTAL CONFERENCE ON ENVIRONMENTAL EDUCATION, Tbilisi (USSR). 1977. *Final Report*. Paris, Unesco, 1978. (Unesco doc. ED/MD/49.)

ISRAEL, R.C.; TIGHE, J.P. 1984. *Nutrition Education: State-of-the-Art. A Review and Analysis of the Literature*. Paris, Unesco (Nutrition Education Series, 7).

JACOBSON, W. J. (ed.). 1986. *Environmental Education: Module for Pre-service Training of Science Teachers and Supervisors for Secondary Schools*. Paris, Unesco. (UNESCO-UNEP International Environmental Education Programme, Environmental Education Series, 7. Unesco doc. ED–86/WS/55.)

MALITZA, M. 1982. Coming Changes in Science and the Curricula. *Prospects, Quarterly Review of Education* (Unesco), Vol. 12, No. 1, pp. 89–100.

MORONI, A. 1978. Interdisciplinarity and Environmental Education. *Prospects, Quarterly Review of Education* (Unesco), Vol. 8, No. 4, pp. 480–94.

REAY, J. (ed.) 1974. *Integrated Science and Teacher Education*. St. Augustine, Trinidad, Unesco/University of the West Indies. (Report of Unesco/CEDO Caribbean Workshop in Barbados, October 1973.)

SOUCHON, C. 1985. Some Thoughts on the New Approaches to Science Education. *Prospects, Quarterly Review of Education* (Unesco), Vol. 15, No. 4, pp. 536–40.

UNESCO. 1983. *Trends, Needs and Priorities of Environmental Education since the Tbilisi Conference: An Overview. Preliminary Report of a World Survey*. Paris, Unesco. (UNESCO-UNEP International Environmental Education Programme. Environmental Education Series, 1. Unesco doc. ED–82/WS/125.)

——. 1986. *Consultation Meeting on the Incorporation of Environmental Education into Technical and Vocational Education, Singapore, March 1986. Final Report*. Paris, Unesco. (UNESCO-UNEP International Environmental Education Programme.)

UNFPA (UNITED NATIONS FUND FOR POPULATION ACTIVITIES). 1984. *Report on the Evaluation of Various Family Life Education Projects with Particular Emphasis on Youth in the English-Speaking Caribbean: Country Reports*. New York, UNFPA.

VAN DER CINGEL, N. 1979. The Education of Teachers of Integrated Science. In: J. Reay (ed.), *New Trends in Integrated Science Teaching*. Vol. 5, pp. 87–96. Paris, Unesco. (The Teaching of Basic Sciences.)

VAN DER VYNCKT, S. 1985. The Role of the Educational System. In: R.C. Hornik (ed.), *Nutrition Education: A State-of-the-Art Review*, pp. 102–4. New York, United Nations.

# Part IV

# Science and technology education and active life

# Introduction

The pivotal role of science and technology education in national development is well established and has been the subject of a number of previous publications by Unesco (Unesco, 1981; 1983). In the five chapters which follow, different approaches to the adaptation of science and technology education to development needs are illustrated.

A recent concern of many countries has been the failure of school science education to demonstrate the potential of science and technology for application in the world of work, and to interest able boys and girls in careers in industry. Kuitunen and Meisalo cite the President of the Finnish Employers' Federation on the importance for industry of enthusiastic, creative and intelligent people coming to work in it. Similar views, coupled with a stress on the wealth-generating role of industry in national economies, have been widely expressed.

Yet in many contexts, the curriculum of general education has deliberately been kept free of industrial influences. It has been feared, for example, that too tight an articulation might move general education to an unacceptable degree in the direction of narrow vocationalism. Indeed, as has been pointed out in a previous chapter (page 101), separate and often parallel systems of general and technical education have frequently been set up.

The problems of establishing fruitful and educationally constructive links between schools and industries are being tackled now in many countries and in their chapter Kuitunen and Meisalo provide a valuable insight into the way that the teaching of physical science at secondary-school level might be adapted so that students acquire a 'better knowledge and understanding of the technology on which production and working life are based'. The activity-based industry visit which they describe depends for its success on many factors, not least much detailed planning in partnership by the teacher and a representative from industry prior to any visit. Students need to be well prepared beforehand, and the focus for their activities in the factory clearly understood. Follow-up after the visit, including reporting to different audiences both orally and in writing, emerges as an important feature of the approach.

It is clear that the time requirements of such structured visits, for both students and teachers, can be considerable. As Kuitunen and Meisalo acknowledge, it would be difficult to justify this purely in terms of improved learning of scientific principles and their industrial applications. The outcomes, however, may be much wider, including, for example, social skills in collaborative group work. There are individual gains also; students may demonstrate a greater sense of responsibility for their own learning and otherwise benefit from the greater opportunities for personal initiative and decision-making.

The forging of constructive links which enable the different cultures of the school and industry to interact in mutually beneficial ways is now being undertaken by science and technology educators in many parts of the world. Technology especially provides opportunities for an injection of realism from industry into otherwise academic classroom and laboratory activities. Small-scale but genuine production, quality control or marketing problems, identified during an industrial visit, can become the starting point for project work in technology. Criteria usually employed to evaluate an artefact resulting from a school technology project can be extended to include 'real-world' considerations, such as the skill level of industrial users, ease of servicing and compatibility with the enmeshing technologies with which it will have to engage. The multidisciplinary collaboration which today characterizes all technological activity in industry can have its counterpart in group technology project activity, in contrast to the individualism of much science education.

That the biological sciences are no less able than the physical to articulate with the world of work is illustrated by Abraham Blum's chapter. He reminds us, first, that agriculture is still the occupation practised by the majority of the world's adult population, and, second, that despite much recent concentration of effort and resources in non-formal education and extension services, schools nevertheless have an important contribution to make to rural development. The agriculturally based science curricula that he describes have the potential to relate to 'man on the land' in a variety of ways including field experiments on common crops (if not on animals) and, most potently, participation in local agricultural development projects entailing the sanction and co-operation of those in the community.

Porfirio Jesuitas, especially in an account of the San Salvador Project, takes the fusion of knowledge and action a stage further by adopting a total community approach to development. All aspects of the life of an impoverished fishing village, not merely food production, come under scrutiny, including health, sanitation, waste disposal, provision of potable water, pest control and fish-stock preservation. In working towards solutions of these problems, scientific and technological knowledge are treated as a resource to be exploited in whatever ways seem appropriate.

In other projects in the Philippines, teaching/learning units have been constructed on indigenous, livelihood-related technologies intended to help students become more self-sufficient and better able to set up small businesses. Interestingly, the logic of relating science and technology to the world of work is taken to its limit here. Within the STEP (Science and Technology Education for Philippine Society) modules, there is one on the basic economics of capitalizing any commercial enterprise on which students might embark on leaving school. Creative localization, including the incorporation of community-based science education, is thus being used to reduce the 'disparity between the goals of science education and the real needs of the society'. At the same time, the Philippine experience illustrated something of the possibilities of informal science education with adults and those who have dropped out of school prematurely.

The theme of informal science and technology education runs through the final two chapters by Taylor and Delacôte. To achieve the shift in public attitudes to science and technology which Taylor deems necessary to meet his four challenges of education for change, awareness, individuality and adventure, a concerted attack across all levels of formal education is required and he offers indications of possibilities here. In addition, however, science and technology need to be seen as permeating many aspects of life. Indeed, they should be regarded as components of general culture, alongside art, literature and music. As an indication of what can be achieved when institutions of science open their doors and welcome visitors, Taylor instances the Science Week at Cardiff University College. Open days, held by universities in many countries, likewise testify to a keen public interest in the research activities of scientists and technologists, especially if these are presented in ways that allow some degree of public participation and do not threaten or patronize non-scientists.

Similarly, the assimilation of science and technology into literature, an aspect of the Bulgarian experiment in interdisciplinarity (see the chapter by Lazarov and Golvoninsky, page 113 above), and into drama and the performing arts, as described by Charles Taylor, can help to bring them into the emotional and everyday lives of non-scientists. As Meyer (1984) has pointed out, sociodrama and creative drama are neglected techniques of out-of-school science teaching with considerable potential both for improving the understanding of subject matter and for the development of communication and interpersonal skills.

The role of science and technology centres has already been mentioned by Ingrid Granstam in her chapter on the education of girls and women (page 47 above). The historic function of science museums has been that of a repository for objects from the past. In recent years, however, a fundamental process of transformation has been taking place with the aim of creating centres of science and technology which are interactive in at least two senses. First, visitors can explore phenomena by first-hand experience, often being able to manipulate and even dismantle and reassemble some exhibits. There is a strong emphasis on involvement and enjoyment. Second, many of the centres relate the principles being demonstrated to the local industrial environment and also to the work of local teachers' centres so that formal and informal educational activities are correlated.

Delacote's description of the Centre for Science and Industry at La Villette, in Paris, one of the most dramatic—and still evolving—examples of the new interactive centres, provides an excellent illustration of such features. Because the world of school subjects and scientific disciplines does not correspond to the way in which the industrial and commercial world is organized, the permanent exhibits are arranged thematically. Special provision is made in an Inventorium for active learning by children between the ages of 3 and 12 years. Industrial companies, both nationally and on a regional basis, provide exhibitions and information. Throughout there is an atmosphere of excitement, exploration and modernity.

Not all such centres have at their disposal the resources to be found at La Villette. Nor would a permanent city site be the appropriate solution in contexts where, for example, a high percentage of the population live in dispersed rural communities. Mobile science and technology exhibitions, such as those of the Visvesvaraya Industrial and Technical Museum, Bangalore, and the Birla Industrial and Technological Museum, Calcutta, have been used to relate science and technology to the problems of village life (Unesco, 1986, pp. 86–7). Irrespective of scale, however, the interactive science and technology centres which have been developed in recent years represent a significant innovation in ways of bringing science and technology into a more intimate relationship with the active life of the great mass of the people.

## References

MEYER, G.R. 1984. The Place of Out-of-school Science in General Education: Current Trends and Future Prospects. In: G.R. Meyer and A.N. Rao (eds.), *Teaching Science Out-of-School with Special Reference to Biology*, pp. 133–50. Singapore/Sydney, International Union of Biological Sciences Commission for Biological Education and Asian Network for Biological Sciences.

UNESCO. 1981. *Final Report. International Congress of Science and Technology Education and National Development, Paris, 1981*. Paris, Unesco. (Unesco doc. ED–81/CONF.401/COL.10.).

——. 1983. *Science and Technology Education and National Development*. Paris, Unesco.

——. 1986. *Unesco Sourcebook for Out-of-School Science and Technology Education*. Paris, Unesco.

# *Science and technology education and industry*

H. Kuitunen and V. Meisalo

Since the early 1970s there has been a worldwide boom in the promotion of school-industry links. The idea has been given wide publicity and there have been several case-studies reporting successful developments. Most of these, however, have been individual ventures involving a single teacher, a particular school or at most one municipality. It has proved difficult to find general strategies for the practical implementation of durable and productive school-industry links.

In Finland since 1979 'education for the world of work and technology' has been a theme of the physics and chemistry curriculum of the *gymnasium* (upper secondary school). Schools and industry have worked together with a model of an industrial visit which is based on active involvement of pupils. We call this model an activity-based industrial visit. The process of national implementation of this model is still taking place and it is apparent that this necessitates a continuous and ever changing effort. The results obtained so far have been very promising both at a local and, most important, a national level. Our experiences and results are described and analysed below.

## The role of science and technology education in schools: the Finnish perspective

### *Education and schools in Finland*

### The education system

The Finnish education system (Fig. 1) is based upon the nine-year comprehensive school, after which there is the possibility of going to either a *gymnasium* or a vocational school. A primary-school teacher is responsible for all the work with a class. From Grade 7 onwards, there are separate subject teachers. At present, approximately half of the students graduating from comprehensive (lower secondary) school proceed to a *gymnasium*. It is significant that both types of school have a tradition of emphasizing the humanities and foreign languages.

## Science and technology in the curriculum

In primary school (Grades 1 to 6), science is taught as an integrated subject. There are possibilities for contacts with local industry, but these depend on the initiative of the teacher.

In the comprehensive school the sciences are taught as separate subjects, each being allocated about one hour per week. The most important form of co-operation between schools and working life is the two-week period of work practice arranged for every pupil.

In the upper secondary school, chemistry and biology are compulsory subjects, each being timetabled for about one hour per week in Grades 10 and 11. Physics and continuation courses in the other sciences are elective. School-industry liaison is organized via physics, chemistry and social studies as well as through the careers guidance and counselling arrangement for students.

## Curricular change

The Finnish school system is rather centralized. All schools adopt the national curriculum. The most recent trend, however, has been to provide more possibilities for local initiatives. Local curricula, for which general features have been prescribed by the central administration, are at present under development. Several municipalities have already adopted a locally modified curriculum in which connections between schools and local industry have assumed a central role, although public discussion on this subject has tended to emphasize local history and local tradition in the arts.

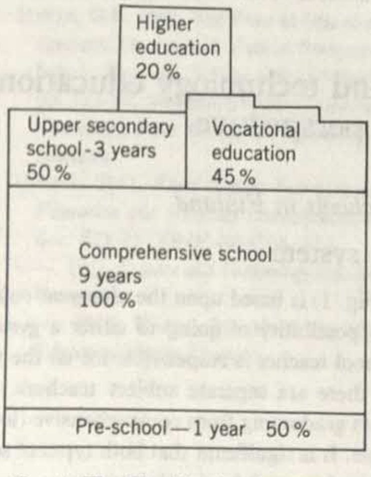

Higher education 20 %
Upper secondary school - 3 years 50 %
Vocational education 45 %
Comprehensive school 9 years 100 %
Pre-school — 1 year 50 %

FIG. 1. The Finnish education system.

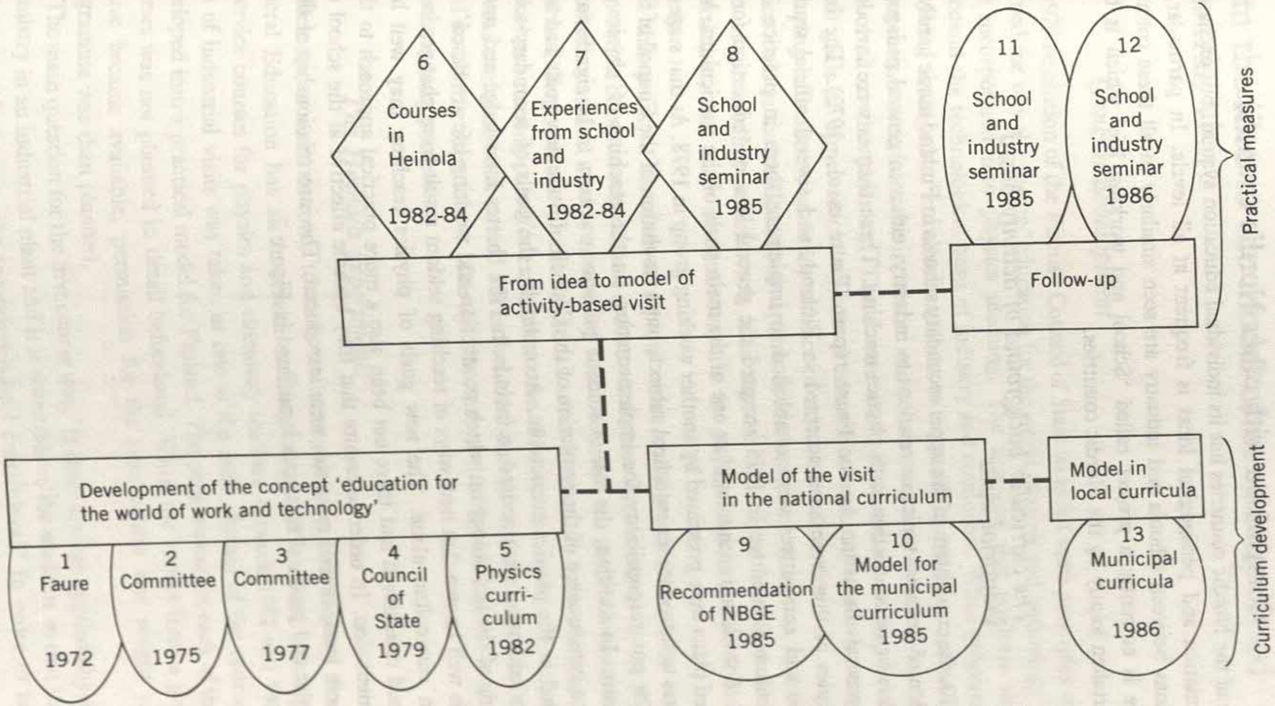

6
Courses in Heinola
1982-84
7
Experiences from school and industry
1982-84
8
School and industry seminar
1985
11
School and industry seminar
1985
12
School and industry seminar
1986
Practical measures
From idea to model of activity-based visit
Follow-up
Development of the concept 'education for the world of work and technology'
Model of the visit in the national curriculum
Model in local curricula
Curriculum development
1
Faure
1972
2
Committee
1975
3
Committee
1977
4
Council of State
1979
5
Physics curri-culum
1982
9
Recommendation of NBGE
1985
10
Model for the municipal curriculum
1985
13
Municipal curricula
1986

FIG. 2. Curricular and practical measures in the development of industrial visits in Finland.

## Comparison with other Nordic countries

Each of the Nordic countries has its individual education system, but exchange of information and pedagogical ideas is frequent at all levels. In particular, the relations between schools and industry are seen similarly in all these countries. There is currently a project called 'School and working life' which is being undertaken jointly by the Nordic countries.

### *The curricular background of activity-based industrial visits*

In 1970, the curriculum of the upper secondary schools in Finland made hardly any mention of practical topics or relations to industry, either in general pedagogical chapters or in connection with physics teaching. These themes were introduced into general discussion by the Faure report (Faure et al., 1972). The broad principles of this were soon accepted in Finland, and several official working groups and committees were established to implement them in practice. The Curriculum Committee in 1975 accepted the general idea of 'education for the world of work and technology' as one of the main goals of the curriculum. More detailed plans were presented by another working group in 1978. At that stage, the idea was to introduce a new school subject, but a resolution of the Council of State in 1979 put responsibility for implementation on the teaching of physics and chemistry. In addition, the role of student guidance was seen to be significant.

As a consequence of the resolution of the Council of State new goals had to be included in the physics curriculum. Accordingly, the goals of secondary-school physics education were revised to include in 1982 'better knowledge and understanding of the technology on which production and working life are based'.

It is well known that new ways of teaching seldom result from changes in the written curriculum alone. The new goals of physics teaching may well have remained unachieved had there not been also a more practical approach to their implementation. In order to ensure that they became effective at the school and classroom level, several measures were introduced. The interrelationship of these curricular and practical measures is outlined in Figure 2.

# From the idea to the model of an activity-based industrial visit

## General development

The 1979 resolution of the Finnish Council of State included some principles which governed the way the theme 'education for the world of work and technology' was to be incorporated into physics teaching. The aim was that students should understand the technological basis of industry and commerce. When programmes were being arranged to introduce students to industrial production and working life, representatives from the industrial and commercial host organizations had to be involved in the planning. There were also considerations arising from the general goals of upper secondary-school education, especially the importance of developing in students an independence of mind, as well as from the nature of physics itself as an intellectual discipline. It was necessary, therefore, to evolve a mode of proceeding which took into account the views not only of local industrialists, but also academic experts in physics teaching and individual students.

At this point, a number of reports were available on attempts to develop co-operation between schools and industry and these were studied. On the basis of the criteria outlined above, an activity which required the students themselves to perform different kinds of investigations when visiting an industrial plant was selected as a starting point for experimentation. The fact that most of the important previous work had been carried out in Sweden meant that the planning was initially based on Nordic experiences. The development of the Finnish national model was to prove a long process.

## The Heinola experiments

At Heinola, a small country town in an industrial area, the National Board of General Education has an in-service training centre for teachers. During four in-service courses for physics and chemistry teachers between 1982 and 1984 the idea of industrial visits was taken as one of the main themes of the courses and developed into a practical model for Finland. The programme for each of the four courses was not planned in detail beforehand. When the results from a previous course became available, permission for the next course was sought and its programme was then planned.

The main question for the first course was, 'Is there enough applied physics and chemistry in an industrial plant and is it accessible to the students so that they can discern its relevance to the secondary-school curriculum?' In order to find the answer, each of eleven plants of different kinds was visited by a group of three or four teachers. The results were very promising: every plant made use of physics and chemistry in different ways and the technical prerequisites for the planned national adoption of the model of industrial visits clearly seemed to exist.

The task of the second course was to explore the possibility of organizing students' own investigations and learning activities in the factories, linked to the school syllabus. The same eleven factories were each visited by groups of four to five teachers. Each group planned together with factory personnel a programme for a visit by students. In all but one case, it was possible to make plans for student-centred work. The experiences gathered during this course were summarized in a scheme for an industrial visit, which is outlined in Figure 3.

Programmes planned by the second course were tested during the third one. Three factory plants were each visited by a group of twenty-two teachers who assumed the role of students during their visits. All the programmes worked well. During the same course students from the local upper secondary school visited another factory plant following the lines of the programme planned by the second course. The audience for students' reports included local and national school

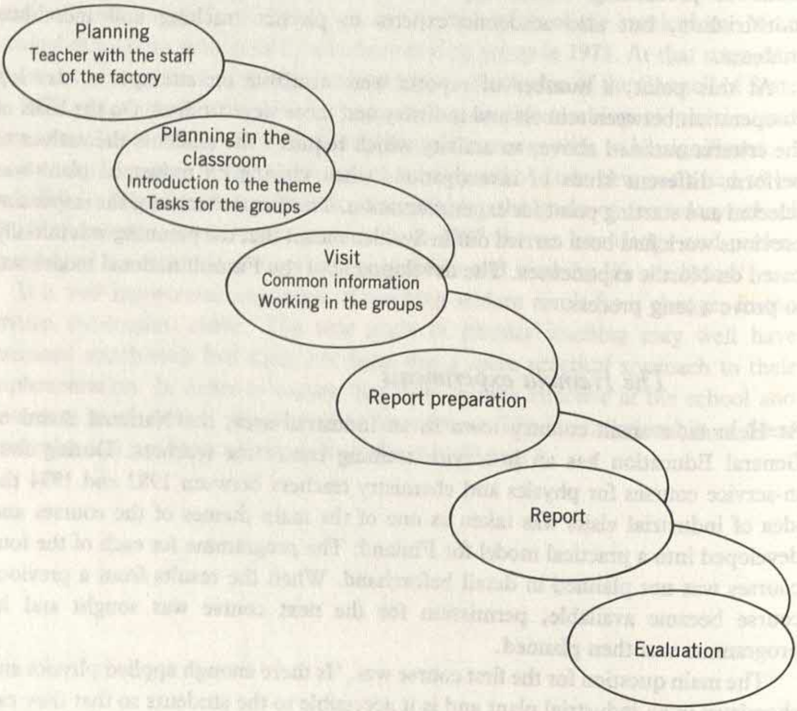


FIG. 3. The scheme for an activity-based industrial visit as developed during the courses at Heinola.

authorities as well as representatives from both teachers' organizations and industry. The students' reports were a great success. It became evident that the model of an activity-based industrial visit was both practicable and reaching the goals as planned. Another most important conclusion was that no simulation could replace the students' own presentations. Teachers and administrators cannot convey to an audience the total impact of a students' visit. This is largely a question of emotions and impressions, and only the students who have experienced the visit can adequately convey these.

No evidence to detract from the favourable impression based on the experiences of the previous courses emerged during the fourth course at Heinola. Here the visits were evaluated by representatives of the teachers, administrators and industrial personnel who had been associated with the visits. The model of an activity-based industrial visit was received with most favourable comments by the audience.

## *The application of the model to general school practice*

After the four courses at Heinola, the model of the visit was tested in a large number of real-life situations; it was found to function excellently. On the basis of our experiences, we can offer some comments on the application of the model in its different phases.

If a teacher is planning the very first visit to a factory, it is important to begin by contacting the company's top management and presenting them with the idea. The next stage of introducing the model includes preparatory planning by the teacher and the factory personnel. It would be easiest for the teacher to visit the factory and be shown round by a member of the staff who will be involved also during the later stages. This guide should provide as much information as possible on the principles of the production processes, testing, maintenance, etc. He also needs to make clear that he is ready and willing to answer any questions. The teacher has to work out how the information received can be related to the curriculum. On this basis, it is possible to identify tasks to be performed by the students themselves. Asking questions and making notes during the tour is also important. After the tour, the two parties sit down together and make a preliminary plan for the visit, deciding where the students may go and what they can actively study during the visit. This agreement is the basis for the preparatory work at the factory.

Subsequent planning in the classroom with the students may be facilitated by the presence of the contact person from the factory. Students are divided into small working groups for the visit, which begins with a tour round the factory, each student group being led by a member of the staff. Students' activities during the visit are highly dependent on local conditions and vary from factory to factory.

Enough time should be allocated for the preparation of a report by each group. This report may take one of several different forms. Most frequently, an oral presentation is used to augment a written report, but sometimes the report is entirely oral or wholly documentary. In the latter case, the report may include material such as a newspaper article or the analysis of a completed questionnaire. In oral presentations, students have used visual aids as well as audio and video recordings. It is clear that reporting always enriches for students the meaning of their visit. If the audience includes people other than classmates, then the occasion of the presentation acts as a stimulus to all involved in the visit. Detailed feedback from and continuing evaluation of the success of the visit are important, especially after the period of initial application of the model has passed and the novelty of an industrial visit is no longer strong.

## Pedagogical research on the activity-based industrial visit

### *Analysis of the characteristics of the activity-based industrial visit*

One of the first tasks of educational research on the activity-based industrial visits has been the analysis of the general characteristics of this kind of visit. Two features are of special interest. First, there is the question of educating young people by providing opportunities for contact with industry as well as demonstrating the relationship between school physics and chemistry and industrial processes. On the other hand, arranging a visit is a practical question and already, at the school level, the operation of the scheme is quite complicated. Interesting practical questions arose in connection with the teacher-school and teacher-society relationships. At the municipal level the question is even more complicated. In all cases, the main problems concern relationships between people.

The model of an activity-based industrial visit is not rigid and allows variation within wide limits. For example, visits have been organized in connection with a wide range of school subjects, some projects even emphasizing content outside the standard school curriculum with notable success. In other cases, teachers have allowed each student group to follow an individual time schedule while working within the industrial plant, whilst other student groups have each visited a different factory. Industrial visits have also been arranged in the form of two-day camp schools. Last but not least, students themselves have contributed in various ways to the dissemination and acceptability of the idea of industrial visits and have raised funds necessary to support the activities.

During the early phase of implementation of the idea, the time spent by a pupil as well as the net teaching time used for an industrial visit were as shown in Figures

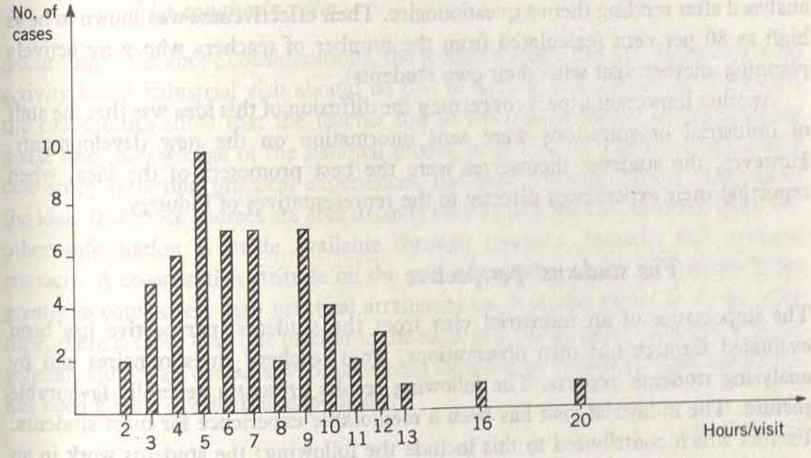


FIG. 4. Distribution of the total time spent by a pupil for a visit.

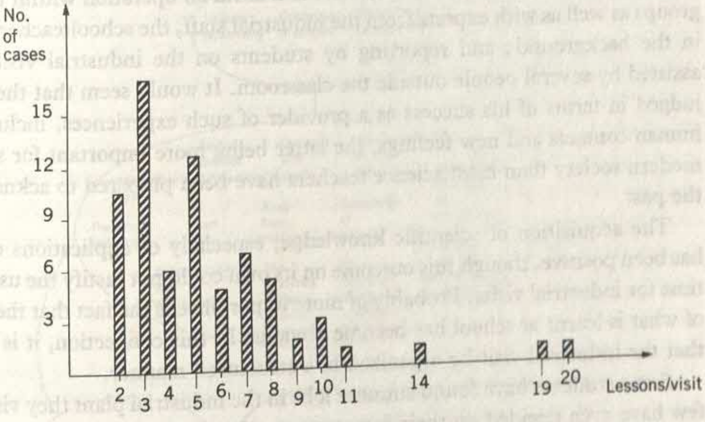


FIG. 5. Distribution of the net teaching time used for an industrial visit.

4 and 5 respectively. The large variations show clearly that there have been widely different forms of visits.

## *Diffusion of the idea*

The dissemination of the idea of an activity-based industrial visit was investigated in accordance with a strategy for studying the diffusion of innovations (Rogers, 1983). The activities of key teachers who had attended the courses at Heinola were analysed after sending them a questionnaire. Their effectiveness was shown to be as high as 80 per cent (calculated from the number of teachers who were actively planning another visit with their own students).

Another important aspect concerning the diffusion of this idea was that the staff of industrial organizations were sent information on the new developments. However, the students themselves were the best promoters of the idea, when reporting their experiences directly to the representatives of industry.

## *The students' perspective*

The importance of an industrial visit from the students' perspective has been evaluated through our own observations, from teachers' questionnaires and by analysing students' reports. The following results present a generally favourable picture. The industrial visit has been a memorable experience for most students. Factors which contributed to this include the following: the students work in an environment which is new for them and in which there is room for personal initiative and decision-making; opportunities are provided for students to take responsibility for their own work; there is fruitful co-operation within the student groups as well as with experts from the industrial staff, the schoolteacher remaining in the background; and reporting by students on the industrial visit has been assisted by several people outside the classroom. It would seem that the teacher is judged in terms of his success as a provider of such experiences, including fresh human contacts and new feelings, the latter being more important for students in modern society than most science teachers have been prepared to acknowledge in the past.

The acquisition of scientific knowledge, especially of applications of science, has been positive, though this outcome on its own could not justify the use of school time for industrial visits. Probably of more importance is the fact that the relevance of what is learnt at school has become obvious. In this connection, it is important that the industrial visit be organized in a structured manner.

Some students have found summer jobs in the industrial plant they visited and a few have even decided on their future career after finding interesting applications and promising career possibilities in the industry. It is especially important for girls to have direct contact with traditionally male careers. Visits have also contributed to general knowledge of industry as well as to an important aspect of their local environment.

General educational outcomes are summarized in Figure 6. It is clear that there are many interrelated factors associated with the pedagogical features of the visits, their goals and the educational outcomes.

## *The teacher's role*

According to the above considerations, the teacher's role in the practical phase of an activity-based industrial visit should be that of adviser and consultant. However, the case-studies show that the teacher has to work hard during the preparatory phase also. Knowledge of the national model, or at least of a previous successful case-study reporting practical experiences, has been essential for the adoption of the idea. In-service courses are able to cover only a small fraction of all teachers, but other information is made available through teachers' journals and personal contacts. A co-operative attitude on the part of contact persons in industry helps greatly in connection with practical arrangements. It is also better if, at the same time, there is more than one teacher in the same area planning an industrial visit. In general, almost all teachers who have been involved in industrial visits feel that it has been a very worthwhile experience.

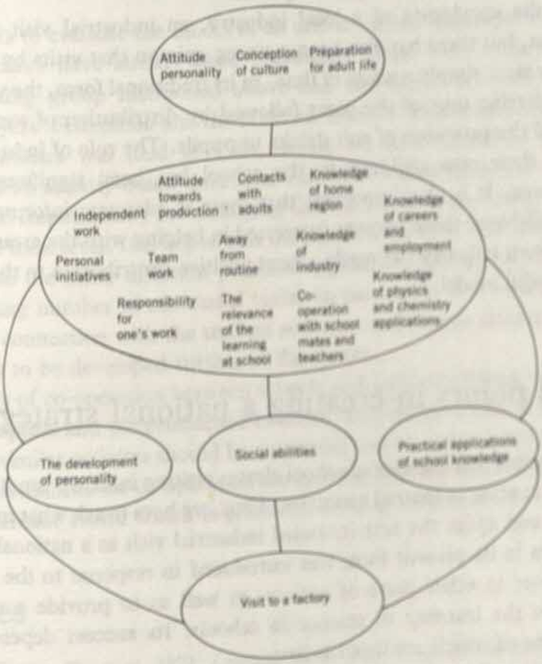

Attitude personality
Conception of culture
Preparation for adult life
Attitude towards production
Contacts with adults
Knowledge of home region
Independent work
Knowledge of careers and employment
Away from routine
Knowledge of industry
Personal initiatives
Team work
Knowledge of physics and chemistry applications
Responsibility for one's work
The relevance of the learning at school
Co-operation with school mates and teachers
The development of personality
Social abilities
Practical applications of school knowledge
Visit to a factory

FIG. 6. The scheme for analysing the general educational outcomes of an industrial visit.

### Viewpoints of industry

It is important that the viewpoints of industry which might have an effect on the success of the visits be analysed. In several discussions, it was noted that the common broad aim for both school and industry was national development. Both parties have their contribution to make, but in the activity-based industrial visits these overlap each other.

Industry obviously would like to change negative attitudes towards industry and technology in general. This is one of the main reasons why industry is willing to participate in such a project. In a follow-up seminar, the President of the Employers' Federation in Finland stated that 'for industry it is important that enthusiastic, creative and intelligent people come to work within it. Our industry regards it very important that young people at a very early age have personal contact with industry.' Several other important reasons include: (a) the public image of the company; (b) the need for qualified manpower in the future; (c) good public relations at the local level; and (d) making industrial products and their quality better known to the general public.

From the standpoint of a local industry, an industrial visit has interesting possibilities, but there has also been a strong opinion that visits by schoolchildren to industry were simply a waste of time. In its traditional form, the visit was often a rapid sightseeing tour of the plant followed by distribution of some information leaflets and the provision of soft drinks to pupils. The role of industrial staff who have had their own children in the school has been significant in the new development. It is also important that there is adequate information and even training available to those persons interested in helping with the arrangements. The feedback from industry has made a most positive contribution to the development of a successful model.

## Crucial points in creating a national strategy

It is well known that the idea of school classes visiting industry is not new, either in Finland or in other industrial countries. Thus, we have to ask what made it possible to develop and adopt the activity-based industrial visit as a national model.

The idea in its present form was introduced in response to the need to bring schools closer to other parts of society, as well as to provide a more practical approach to the learning of science in schools. Its success depended on many factors, some of which are listed below:

The resolution of the Council of State provided strong authoritative support.
This resolution was parallel to general trends in the development of science curricula.

- The contribution of industry, especially of one national chemical company, was crucial.
- The national employers' organization was active from the beginning and contributed to the success of the project throughout the development process.
- The Heinola In-Service Centre provided excellent surroundings for the development of the model.
- The teachers' organization contributed actively by disseminating information to its members.
- An unofficial working group was created to promote the diffusion of the idea. This included members from school administration, central organizations of industry and teachers' organizations.
- The time was ripe for this kind of approach: industry had a strong will to participate and schools were looking for contacts with other parts of society.

## The future of school-industry links

Several seminars to evaluate the model of an activity-based industrial visit and its associated practices have already been organized. These were initiated by the unofficial working group mentioned above and the organizers have been the Finnish Employers' Federation and the National Board of General Education. The first of the seminars was held in 1988. While we have described above the development of an activity-based industrial visit from a local project to a national programme, the responsibility for arranging the visits will in the future rest more and more at the local level. It is hoped that the model will prove sufficiently flexible to accommodate the many different practical approaches that are likely to result from the growing number of successful visits. In particular, it is anticipated that innovations in connection with the student activities undertaken during industrial visits are likely to be developed further in the future.

Other forms of co-operation between schools and industry include training for chemistry olympiads and the production of some teaching materials. It is intended that these and similar activities should be continued and be more widely used in the future. New possibilities for co-operation are opening up following the creation of a new national science centre which is gradually starting its operations.

## References

Faure, E., et al. 1972. *Learning to Be. The World of Education Today and Tomorrow.* Paris/London, Unesco/Harrap.

Rogers, E.M. 1983. *Diffusion of Innovations.* 3rd ed. New York, The Free Press.

## Further reading

BASSOW, H. Bridging the Industry-High School Gap. *Journal of Chemical Education*, Vol. 61, No. 4, 1984, p. 367.

HARRISON, G. The Role of Technology in Science Education. In: C. McFadden (ed.), *World Trends in Science Education*, pp. 18–26. Halifax, Nova Scotia, Atlantic Institute of Education, 1980.

KUITUNEN, H. Visit to Industry, Based on the Pupils' Own Activity, and its Diffusion in the Senior Secondary School in Finland. (Paper presented at the Third International Symposium on World Trends in Science and Technology Education, Brisbane, Australia, December 1984.)

——. A Visit to a Factory as a Part of Physics and Chemistry Education and its Learning Outcomes in the Senior Secondary School in Finland. *Proceedings of Nordic Conference of Science and Technology Education, Karslunde Strand, Denmark*, pp. 8–12. 1985.

NAE, H.; MANDLER, V.; HOFSTEIN, A.; SAMUEL, D. Chemistry in Action. How to Plan a Visit to the Chemical Industry. *Journal of Chemical Education*, Vol. 59, No. 7, 1982, pp. 582–3.

UNITED KINGDOM. DEPARTMENT OF EDUCATION AND SCIENCE. *Schools and Working Life. Some Initiatives*. London, HMSO, 1981.

# *Science and technology education and agriculture*

### Abraham Blum

## Science and technology: two basic approaches

The *Oxford English Dictionary* defines technology as 'the scientific study of the practical or industrial arts', but also as 'application of science'. I like these definitions because they stress the dual character of technology. We can look at technology as an application of science, but also as a science in its own right; one that explains the practical arts. Both aspects have important implications for science and technology education. If we prefer the first definition, we shall emphasize in our educational programmes the application of scientific principles and findings to practical life, and especially to those industries having the strongest bearing on our students. However, we might also teach technology as a special brand of science, namely, one that deals with practical arts. In that case, we want students to study the way practical arts and technologies develop, what factors effect their evolvement and what their impact is on human life and on the environment.

Technology is older than science. Wise men knew how to heal before medical academies were founded. Our ancesters made excellent tools without having studied metallurgy. Parents and teachers educated children before pedagogics was recognized as a science and educational methodology became dominated by instructional technology. The same is true for agriculture. The 'invention' of sowing was one of the greatest human achievements. Astute peasants knew how to select the best seeds for propagation long before genetics was developed. Their wives made cheeses and many fermented products long before biotechnology became a discipline. Any history of science must recognize that its roots are deep in the primitive technologies of human experience.

What, then, is the main contribution of modern science to those ancient technologies, such as agriculture, which preceded it? It is scientific methodology. Before the scientific revolution, progress was based on *experience* alone, which is an accumulative process and, therefore, time consuming. Modern science (in contrast to Greek and Eastern thought) is based on *experimentation*. Both experience and experimentation have the same semantic and substantive root. Both demand careful observation and intelligent drawing of conclusions. However, learning by trial and error takes up a lot of time, whereas planned experimentation allows for quicker and more reliable deductions. Here lies the advantage of modern science and its application to all technologies over the more intuitive use of experience in pre-scientific societies.

## Agriculture as technology and science: implications for education

Agriculture is the second oldest practical art in the world. Only food collecting, hunting and fishing are older. It is interesting to note that the fine arts developed in parallel to the practical arts and in close relationship with them. The first cave drawings known to us glorify the skills and marvels of the craftsmen of the day and their experiences when hunting wild animals with simple tools. From the dawn of human history, contemporary technologies have occupied the best minds and the finest artists. Until the agricultural revolution, the main theme was food gathering and hunting. Between this and the industrial revolution, agriculture and other practical arts developed side by side. After the industrial revolution, technology focused on mechanical arts and now we seem to have moved into the age of the electronic arts. It has to be remembered, however, that this latter stage applies to only a minority of people in the world; the majority are still concerned with the production of food for a fast-growing world population. The study of agriculture's role as technology and as science is therefore a topic which should concern science educators in both so-called developed and developing countries.

In the industrialized countries, science educators can use agricultural technologies to show how science has turned an ancient and basic art into a mechanized and sophisticated technology. Students can study how agronomists and other researchers have influenced plant behaviour by applying scientific principles to enhance the quantity and quality of food production and of ornamental displays.

The World Conservation Strategy has introduced an important new term, 'sustainable development'. It acknowledges the need for further development, especially in low-income countries. At the same time it stresses the need to check carefully whether this development is really sustainable. Conservation education and its newer version, environmental education, have had a strong impact on science education. Environmental science has been infused into more science education programmes than into all other subject curricula together. Although sound agricultural practices conserve the soil and keep the land fertile, agriculture can also be a menace to the balance of nature. This is a problem that concerns both rural and industrial societies. In the former, soil erosion, often triggered by deforestation, is destroying the most valuable asset that these countries have. In industrialized societies science educators seem to be well aware of the negative effects that modern agriculture can have on the environment. The pesticide problem and that of surpluses of artificial fertilizers, which kill life in streams and rivers, and threaten the groundwater, have been topics in science education programmes in various countries. Typical examples are the Conservation Education Project (Kelly, 1975) and *The Ridpest File* (Bath University, 1976) in the United Kingdom; a unit on agriculture and the environment being developed at the Institut für die Pädagogik der Naturwissenschaften in the Federal Republic of Germany as part of a biology education project; and the Agriculture as Environmental Science project in Israel. In most of these units, the personal value positions of the authors, ranging from advocacy of the use of chemicals in agriculture, through an integrated, balanced view to a rather anti-farmer approach, come through.

Another powerful focus for integrating agricultural issues into science curricula is development education. Many educators in industrialized countries are concerned about the unequal distribution of food between the poor and rich countries, and the growing danger of a world hunger calamity with all its international repercussions. This has led to the creation of curriculum units in which the potential of improved agriculture is studied in the context of development. Typical examples are the Food for a Growing Population unit in the Science in Society Project in the United Kingdom (Association for Science Education, 1981), and the Fight Hunger unit in the Israeli Agriculture as Environmental Science curriculum. However, much as development education is a commendable constituent of science and technology education, its applied facets are a must in rural, developing nations.

## The sad state-of-the art

Thirty-eight countries with a population of 1,300 million people are termed low-income countries. Their average per capita gross national product (GNP) is $200 a year. They are spread over Africa, Asia, Latin America and Oceania, but have many things in common; above all, they are poor and possess an agrarian economy. Three out of four people work in agriculture, but they produce less food per capita today than they did ten years ago, in spite of the Green Revolution. Some 450 million people are undernourished and every year millions of children die of hunger, or suffer from malnutrition.

The only hope for a long-range improvement of the economic situation of these countries is appropriate rural development. Even in countries where oil or important mineral deposits have been discovered, the rural sector comprising the majority of the people has remained poor and undernourished, and the social gap has widened.

Much has been written about the Green Revolution (e.g. Dahlberg, 1979) and the development of high-yield varieties of rice, wheat, maize and other major crops. This, in itself, has been one of the major achievements of applied science. The potential of these new varieties is high and some of the most populated countries on earth have raised their yields dramatically. But, as with all assumed panaceas, backlashes occurred and basic problems became obvious. To justify their name, the high-yield varieties demand intensive cultivation methods involving the use of fertilizers and other purchased inputs, as well as more knowledge. Both capital and modern know-how are not easily available to the majority of rural dwellers in developing countries. Even if governments, development banks and co-operatives provide loans and the necessary infrastructures, the crucial point remains: more knowledge is needed, especially skills in applying new science-based rural technologies.

Who is going to teach the hundreds of millions of youngsters who will have to grow food for their families of tomorrow, the science and technology they will need to fulfil their prime task in life? It would appear obvious that this should be one of the main challenges of school, requiring the powerful tool of science education. Yet, schools in many developing countries go on teaching science for the very small percentage who will take up a scientific career and neglect the vast majority of pupils who need appropriate knowledge in science and technology applicable to agriculture. They adapt science curricula from highly industrialized nations which have become curricular powers, and even make use of culturally foreign examinations (Bloch, 1978; Blum, 1979*a*; Williams, 1979). The textbooks written for these new science curricula contain little about the scientific and technological problems that most pupils will encounter in their lives in connection with agriculture. The frontispieces of some of these books depict, typically, men walking on the moon instead of people working in their fields.

Rural secondary schools in many of the developing countries train the gifted village boys for future life in the city, and drain the villages of their best potential for local leadership. Only a minority of education policy-makers seek a non-alienation of rural youth and work towards the villagization concept, as did the Solomon Islands Education Policy Review Committee (1973) in their attempt to maintain their way of life while improving it through consideration of alternatives from other parts of the world.

Part of the problem lies in the separation of pure or conventional science teaching from agricultural education. Unesco recommended that pupils should be assured of the equivalence of agricultural and general science courses (Unesco, 1980, p. 38) but in reality 'in many cases, agricultural education makes for social segregation' (Malassis, 1975, p. 212).

It is no wonder that leading development experts have written off or doubt the effectiveness of the school as a partner in rural development in developing nations, and have put their money into extension services and other forms of non-formal education (Coombs et al, 1973). Although the latter have made some very encouraging breakthroughs, schools nevertheless still have their advantages: they reach into areas not served by extension, they have prestige, and, if teachers get the right kind of training and support including suitable curriculum materials, they can achieve notable results.

Many science curricula in developing countries have not yet taken up this challenge. They were strongly influenced by major American and British science curriculum projects and publishers who were ready to extend their help (Blum, 1979*a*). Even in those situations where the adaptation of European science curricula to the conditions of developing countries was well done, as in the Caribbean and Swaziland with Scottish Integrated Science, the potential of agriculture for achieving realistic science teaching was neglected. Still more regrettably, even where science curricula with agricultural themes and developmental attitudes have been introduced, the needed teacher retraining has often not been adequate.

## Different approaches

It has been suggested (Unesco, 1980, p. 38) that science and agriculture teachers 'ought to meet regularly to discuss and adjust the cross-references of their respective subjects. Problems encountered in the agriculture course will be studied in the science course.' This team-teaching approach, aiming at a fruitful interaction between teachers who constantly co-ordinate their lesson planning, is a beautiful dream, but far removed from reality. Unless the two subjects, agriculture and science, are correlated at the curriculum level, the gap will not be bridged in most cases.

A more realistic approach is to *integrate* agricultural science into the conventional science curricula. This can be done by using agricultural topics: (a) as a leitmotif around which a science curriculum is built; (b) as optional agricultural chapters in a conventional science curriculum; or (c) as a strand, parallel to biological, chemical or other strands which are part of a co-ordinated science curriculum. Some examples are given below.

A typical example of the first integrated approach is Owen's (1973) *Agricultural Science for Zambia*. From the first chapter on, simple agricultural experiments are introduced. The author points out that the study of this subject is not just for the rural dweller, but is important for all the citizens of a country. He goes on to say that the knowledge can be passed on to the people in the villages to help them improve their methods. As in most agricultural science courses, practical issues are emphasized at the cost of other science issues, even basic ones, which are also important, especially if an equal status to the accepted form of science teaching is sought. The assumption is that prestigious pure science is taught in an unco-ordinated, parallel course.

The *Agricultural Science Materials Project* of the Australian Curriculum Development Centre takes another interesting approach. Modular units treat, among other subjects, 'basic' biological topics such as plant anatomy and physiology or genetics, emphasizing agricultural examples. Other units have a clear agricultural-technical orientation for example, the booklet on horticulture. Of special interest are innovative units on 'the farm ecosystem' or 'discussing and deciding—the farmer as decision-maker'. Here, another trend in science education, namely, relating science, technology and social decision making, is exemplified in the agricultural science programme.

*A life and agricultural science curriculum* which treats the whole range of biology but is based on an agricultural approach (where feasible and practical) including interwoven chapters on economics, was developed in Israel (Israel, 1980). It is an alternative to the Biological Sciences Curriculum Study (BSCS) based high-school biology curriculum. In order to ensure an equivalent status, parallel examination status was sought and achieved. The Inter-University Board on Student Admission accepted it as one of the science options (besides physics, chemistry, and biology), which would fulfil their minimum science requirements for university entrance. Since in Israel science curriculum project staff are heavily involved in the writing of the examination papers, the chances that the examinations reflect the spirit of the curriculum are good.

An example of *an agricultural chapter in a modular science course* is 'The influence of agricultural activities on soil erosion', developed at CENAMEC (1979), the National Science Teaching Improvement Centre in Venezuela. The student manual starts with an explanation of why soil erosion is such an important topic in some of the agrarian areas of Venezuela and why the problem should be studied from the point of view of various disciplines: climatology, geology, soil science and ecology. Accordingly, the learning and teaching materials are divided into four modules, each of which centres around one of the four disciplines. The need to sensitize students to the problem by involving them in the planning aspects emphasized in the teacher's manual.

In Fiji, agricultural science is part of a system which features elements of a combined science-teaching approach in which two parallel and interlocking curricula are co-ordinated. Besides the *Basic Studies*, which include basic science, *Modern Studies* were also introduced (Ram, 1972). The basic science course was developed by Unesco and the University of the South Pacific. It is used also in other

Pacific Islands. Although the project leaders (Stamp and Muralidhar, 1979) of the science series state in the introduction to the science readers that they are concerned with key areas of South Pacific resources, technology and agriculture, only a few agricultural references can be found. Even in the booklet on plant products, which emphasizes essential oils, spices and dye-stuffs, not much is said about the cultivation of these plants. This approach is counterbalanced by the parallel Modern Studies units, for example, 'The coconut', 'Growing meat chickens' or 'Profits from plant nurseries', produced by the Curriculum Development Unit of the Fiji Department of Education. The Modern Studies units were successful (Sutherland, 1977) in integrating principles of modern, scientific agriculture with techniques of production and in involving pupils in practical project work based on sound economic lines.

Probably the most established agricultural science curriculum with a wider focus on developmental, science and society issues is the *Agriculture as Environmental Science* curriculum in Israel, which is co-ordinated with the biology and the physical sciences curricula of Junior High Schools (Israel, 1978). Some of the units, such as those on the world hunger problem or on plant protection (featuring the dichlorodiphenyltrichloroethane (DDT) controversy), appear as options in both the agriculture and the pure biology curricula of grade 9 (age 15). All three parallel curriculum strands of the junior high-school science complex were developed by teams of the same national Curriculum Centre. When the co-ordinated agricultural science curriculum project started in 1966 it was considered a revolutionary innovation compared with the familiar rural studies type of gardening course. But over a period of time it received scientific respectability and changed pupils' attitudes towards the problematic school subject of agriculture. This change in respectability followed the recognition that agricultural science was in no way less scientific, but certainly more relevant to social and developmental issues, than conventional science courses. This set the stage for the full integration of agriculture and biology in the later upper-high-school, Life and Agricultural Science, curriculum mentioned above.

## Successful techniques

Various techniques are being used to let pupils experience how agricultural knowledge is created and used for rural development.

*Field experiments* are the most important technique. They can be simple and very meaningful. They start with common crops which are used in subsistence agriculture and with simple improvements which cost nothing or very little, but can improve yields considerably. For instance, where row planting is still uncommon, its advantages can easily be demonstrated by simple, comparative field experiments. Other simple topics include the use of compost or fertilizers, discovering the optimal spacing between root crops and comparisons between varieties of plants.

One can start with qualitative experiments and training in observation skills and then go on to quantitative field trials which demand more measurements. One can even try bi-factorial designs if interactions between two factors are to be studied. Some of the latter experiments have been devised for schools without the need for statistics.

Probably in most school field experiments one would use controls or comparison plots. Then the idea of repetitions (which are made concurrently in field experiments) is introduced to show how one can overcome experimental design problems such as unequal soils and related factors. To learn how to sample can be fun. Sampling is usually connected with drawing lots and similar games.

Improvements in existing subsistence crops, which are demonstrated in school plots and which can be seen by parents and neighbours, have the best chance of influencing rural development. Yet, socio-cultural factors can be a hindrance. In many developing agrarian countries, subsistence farming is left to the women. Men do some of the physically more demanding jobs; they are in charge of marketing and, if they grow crops, these are usually cash or export crops. In order to attract boys to agricultural science, the latter crops (coffee, cocoa, tea, rubber, palm-oil, etc.) should be kept on the school farm and be subject to experimentation. Since most of these crops are perennials, serious problems of space and investments arise (Bergmann, 1978).

What has been said about plant experiments is, in theory, also true for experiments with domestic or marine animals, but experiments with animals are more difficult to handle, are more apt to be invalidated by unplanned interferences from outside and sometimes pose moral problems if the experiments involve any cruelty. Keeping animals in school poses specific maintenance problems, but the fact that they are alive and moving makes them more attractive than plants to many pupils (Kelly and Wray, 1971).

Field experiments should be supplemented by related *laboratory or classroom experiments*. The most widely used are soil and germination experiments; but issues in plant protection, breeding, growth hormone effects and many other relevant topics which are basic for agricultural development have also been investigated in classroom experiments. Because these experiments are quite similar to experiments carried out in ordinary science teaching, we shall not go into more details here.

*Games* are often used in science education when dealing with more complex and especially social and cultural problems which cannot be investigated experimentally. While learning games can be as effective in agricultural science as in science teaching generally (Blum, 1976, 1979*b*), games are especially appropriate to the simulation of developmental issues. The experience with the End to Hunger game of the Agriculture as Environmental Science project, and with many other developmental games, has shown their value as peak learning experiences. The most appropriate types of games are role plays to understand how different interests clash; simulation games which create an atmosphere of interaction; and planning games in which an optimal solution has to be worked out. Often in development problems a solution has to be chosen from among various possible alternatives. For this purpose various techniques for training in decision-making can be used, for example, decision trees, cost/benefit analysis, case-studies and decision kits.

The involvement of pupils in rural development reaches its peak when they actually take part in *a real development project*. In some countries the idea of education for self-reliance (see Nyerere, 1968), and the concomitant need for pupils' help in financing their school by raising agricultural crops, has been widely accepted (Muller, 1980). However, in practice pupils can get the feeling that they are exploited if self-reliance is enforced and if the educational message does not reach the audience. Alternatively, pupils co-operate but remain passive. After pupils in the higher forms have studied the principles of scientific investigation and have discussed the problems of agricultural development, they should be challenged to apply the knowledge gained in a field experiment to solve a real local problem (even if it is a small one). This can be done in the form of a small, local project, first as a proposal and then in reality, after having secured the co-operation of those in the community who have to sanction the project or can help in its implementations.

*Popular scientific and technical literacy* is another skill which is often neglected. If schools really want to prepare pupils to be able to acquire new and useful knowledge in their adult life, they must give them the tools to do so. In a farming, developing community this means that school-leavers must be able to read simple pamphlets published by the advisory services and hopefully, farmers' magazines. Scientific literacy is a problem even in developed countries, and recently a concentrated effort has been made to deal with this issue by involving science teachers (Association for Science Education, 1980). The question of how to teach pupils to read texts which use technical and popular scientific terms and of how to motivate them to do so still needs serious study, but some attempts have been made. No doubt this is another challenge to science teachers who are committed to the idea that they can and should show how science and technology contribute to rural development.

## Conclusion

Two main obstacles prevent science teachers, as a whole, from taking a more active part in science and technology education for development. First, their primary allegiance is directed towards their own reference group and not towards the needs of the vast majority of their pupils. Second, appropriate curriculum materials are not abundant. Yet, as more and more relevant approaches and techniques in the field of science education for rural development emerge, are tested and become available, the arsenal of adaptable curricula and learning-teaching materials grows.

Three things are needed to give this movement momentum:

More backing by the educational and political leadership in developing, agrarian countries for changes in goals and priorities in favour of an agriculturally based science curriculum and closer co-operation between schools and development agencies.

More international dissemination of rural-agricultural science education curricula, units and evaluation reports, perhaps with the help of a specialized clearinghouse, which so far does not exist.

More study, knowledge and training in the art of adapting existing approaches, techniques and units to different ecological and socio-cultural conditions.

## References

ASSOCIATION FOR SCIENCE EDUCATION. 1980. *Language in Science*. Hatfield, Association for Science Education. (Study Series, No. 16.)

——. 1981. *Science in Society*. London, Heinemann Educational. (Teacher's Guide and Readers.)

BATH UNIVERSITY SCHOOL OF EDUCATION/BRITISH AGROCHEMICALS ASSOCIATION. 1976. *The Ridpest File*. Loughborough, Tecmedia Ltd. (Marketed by British Petroleum Educational Services.)

BERGMANN, H. 1978. Agricultural Instruction in Primary Schools: A Contribution to Rural Development? *Development and Cooperation*, No. 2/78, pp. 9–11.

BLOCH, J.A. 1978. *To a Model for the Adaptation of Curriculum Materials and its Use in the Work with 'Individualized Science' in West Germany*. Kiel, Institut für die Pädagogik der Naturwissenschaften.

BLUM, A. 1976. A Game to Teach the Life Cycles of Fungi. *Journal of Biological Education*, Vol. 10, No. 4, pp. 203–7.

——. 1979*a*. Curriculum Adaptation in Science Education: Why and How. *Science Education*, Vol. 63, No. 5, pp. 693–704.

——. 1979*b*. The Remedial Effect of a Biological Learning Game. *Journal of Research in Science Teaching*, Vol. 16, No. 4, pp. 333–8.

CENAMEC (Centro Nacional para el Mejoramiento de la Enseñanza de la Ciencia) 1979. *Influencia de las actividades agrícolas en los processos erosivos del suelo; unidad modular. Versión experimental*. Caracas, CENAMEC.

Coombs, B.H.; Prosser, R.C.; Ahmed, M. 1973. *New Path to Learning for Rural Children and Youth*. New York, International Council for Education Development.

Dahlberg, K.A. 1979. *Beyond the Green Revolution: The Ecology and Politics of Global Agricultural Development*. New York/London, Plenum Press.

Israel. Ministry of Education and Culture. 1978. *Agriculture as Environmental Science. A Curriculum Project*. Jerusalem, Curriculum Centre.

——. 1980. *Life and Agricultural Sciences Curriculum*. Jerusalem, Curriculum Centre.

Kelly, P.J. (ed.). 1975. *People and Resources*. London, Evans Brothers.

Kelly, P.J.; Wray, J.D. 1971. The Educational Uses of Living Organisms. *Journal of Biological Education*, Vol. 5, No. 5, pp. 213–18.

Malassis, L. 1975. *Agriculture and the Development Process. Tentative Guidelines for Teaching*. Paris, Unesco.

Muller, H. 1980. Teaching Self-reliance. *Development and Cooperation*, No. 4/78, pp. 26–7.

Nyerere, J.K. 1968. *Ujamaa*. Oxford, Oxford University Press.

Owen, G.H. 1973. *Agricultural Science for Zambia*. Lusaka, Longman.

Ram, H. 1972. *Directives on Curriculum Development—1.1.72*. Suva, Ministry of Education, Youth and Sport.

Solomon Islands Education Policy Review Committee. 1973. *Education for What?* Honiara, Solomon Islands Government Press.

Stamp, A.; Muralidhar, S. (eds.). 1979. *Unesco-USP Science Series*. Suva, Fiji, University of the South Pacific Institute of Education.

Sutherland, J.A. 1977. Changing Pattern of Secondary Education in the Pacific Islands. Address to the New South Wales Chapter of the Australian College of Education, 20 October 1977. (Mimeo.)

Unesco. 1980. *Education in a Rural Environment*. 2nd ed. Paris, Unesco.

Williams, I.W. 1979. The Implementation of Curricula Adapted from Scottish Integrated Science. In: P. Tamir, A. Blum, A. Hofstein and N. Sabar (eds.), *Curriculum Implementation and its Relationship to Curriculum Development in Science*, pp. 295–8. Jerusalem, Amos de Shalit Science Teaching Centre, Hebrew University of Jerusalem.

# *Science and technology education for living*

Porfirio P. Jesuitas

## Introduction

It is widely recognized that science and technology are two of the most important contributors to a country's development. They can only prosper, however, when a suitable environment for their growth and development has been created. This necessitates popular acceptance of the role played by science and technology in national development and in improving living standards.

## Science and technology in everyday life

Science and technology have reached into even the most rural areas in most developing nations. In the Philippines, for instance, farmers sow seeds of high-yielding, disease-resistant varieties of rice and other crops, and use pesticides and fertilizers. Housewives use contraceptives, have their children vaccinated and use detergents to wash their clothes. Most people take a 'jeepney' or a tricycle to travel about. Young and old, men and women, turn on a transistor radio to listen to their favourite radio programmes, music, news and farming hints, commentaries and soap-operas.

In the cities and suburbs, people delight in their videotape recorders, watching movies at home. They enjoy seeing the latest films in air-conditioned rooms or *salas*, eating cakes or cookies fresh from the oven and cold drinks straight from the refrigerator. Other adults and children are occupied with computer games.

The less well-to-do, however, still spend much time watching television. They are often amazed by programmes transmitted directly across the world by satellite.

Back in their workaday world, fathers drive their children to school and rush to their offices in sleek cars. Meanwhile, mothers supervise their maids as they do the family laundry using a washing machine and drier. The maids also clean the house with a vacuum cleaner. When they cook the family meals, they use a rice cooker, a microwave oven or a cooking range.

Science and technology have indeed touched the lives of most Filipinos. Very few, however, are well prepared for the best and the worst that science and technology may bring.

## Science and technology through formal education

Education plays a crucial role in bringing science and technology closer to the people although, for many children, primary-school education is all the formal schooling they receive. In the Philippines there are at present 8.7 million pupils of whom only 3.2 million are high-school students. According to published statistics, only 65 per cent of those who enter Grade 1 complete primary school (Grade 6). About 56 per cent go to high school, but only 41 per cent stay on long enough to complete their fourth year. Some 39 per cent reach the tertiary level of education, while only 12 per cent finish a four-year course. Clearly, if education is to help produce a scientifically and technologically orientated citizenry, science and technology must be included in the primary-school curriculum.

Science has always been a part of a child's experience in school. Science subjects help a child gain a functional understanding of the concepts and principles linked with real-life situations, and acquire science skills as well as scientific attitudes and values needed in solving everyday problems pertaining to health and sanitation, nutrition, food production, and the environment and its conservation.

The final report of the meeting of experts on the incorporation of science and technology in the primary-school curriculum convened in Paris in June 1980 gave several justifications for the inclusion of science and technology in the primary science curriculum including the following (Harlen, 1983, p. 189):

Science can help children think in a logical way about everyday events and to solve simple practical problems. Such intellectual skills will be valuable to them wherever they live and whatever job they do.

Science, and its applications in technology, can help to improve the quality of people's lives. Science and technology are socially useful activities with which we would expect young children to become familiar.

As the world is increasingly becoming more scientifically and technologically orientated, it is important that future citizens should be equipped to live in it.

Science, well taught, can promote children's intellectual development.

# The role of ISMED in science and technology dissemination

How can science and technology education contribute to improved living standards? Experiences of the Institute for Science and Mathematics Education Development (ISMED) of the University of the Philippines gained from its many community-based projects show that science and technology education can contribute significantly to raising community living standards.

The years 1977–79 saw the gradual transformation of a remote poverty-stricken fishing village into one with substantially improved living standards.

## *The San Salvador Project*

San Salvador is a small village off the main island of Iloilo province in the southern Philippines. The adults in the community made their living using marginal fishing methods. The village had no electricity. People got their water from a few shallow wells or a large cement tank which stored rainwater. Water was sometimes brought in by boat from the main island town of Banate. There were no health facilities. The nearest clinic was a considerable distance away and to reach it one had to travel by pumpboat. About 87 per cent of the population had no toilet facilities and 73 per cent disposed of their rubbish by dumping. The sole primary school had 270 pupils enrolled. School officials and extension workers rarely came to visit the school. No magazines, newspapers or other reading materials reached the village regularly. Because of the community's utter poverty, villagers had practically no alternative ways of earning a living and few opportunities for leisure activities and education. They had hardly any chance to improve the quality of their life.

ISMED conducted a needs and resources assessment of the community. The following parameters were included in the assessment: economic activities; use of indigenous technologies; community structure; status of health and sanitation; community resources; beliefs and practices about nature, occupation, life, environment, entertainment and leisure-time activities; and perceived socio-economic constraints in the community and expressed needs of the village people. The methods used in the assessment included in-depth interviews, questionnaires, group sessions and visual inspection.

The data were analysed to identify problems and implications for the curriculum development/planning. Table 1 shows an analysis of data to identify curriculum needs (Hernandez, 1978, 1980*a*, 1980*b*, 1982).

Seminars and workshops were conducted for the adults of the community. These dealt with topics on appropriate fishing methods, making encircling gill

TABLE 1. Analysis of data to identify curriculum needs (Sample community: fishing village)

| Data | Problems | Implications for curriculum | Implications for non-formal education (adults) |
|---|---|---|---|
| Analysis of drinking water from all sources revealed an infinite number of coliform bacteria per 100 ml of water. | Source of drinking water: shallow wells and a few tanks for catching rainwater running off from galvanized iron roofs of some houses. | Awareness about micro-organisms in the community's water supply.<br>Knowledge about micro-organisms and their role in the spread of disease.<br>Methods of keeping water safe to drink.<br>Solar distillation of water to demonstrate the purification of water, the water cycle and the production of pure water for emergencies. | Contacting the National Administration to present the community's problem.<br>Demonstration of ways of making water potable: boiling using clean containers.<br>Sanitation activities to keep water free from faecal contamination.<br>Discussion of results of water examination with adults; also health implications. |
| Respondents lacking skills and knowledge in:<br>fishing gear methods—78 %<br>controlling respiratory diseases—61 %<br>controlling pests and other insects—56 %<br>good water supply—56 % | Low catch of fish.<br>Small size of fish caught.<br>Idle unrepaired machines.<br>Children frequently ill.<br>Large population of insects: mosquitoes and other pests. | Comprehension of biology of local fishes (life cycle, habitat).<br>Identification of common fishes of the locality.<br>Methods of fish capture.<br>Awareness about the need of preservation of fishing grounds, avoidance of overfishing. | Seminar-workshop on fishery education using local resource persons from government fish extension bureau/projects in the nearest city or town.<br>Content of seminar included: improved fishing gear and methods, e.g. making encircling gill nets, outfitting fishing boat with pump-engine for deep-sea fishing. |

| Data | Problems | Implications for curriculum | Implications for non-formal education (adults) |
|---|---|---|---|
| | | Knowledge of means of preserving fish applicable to locality.<br>Knowledge about parasitic diseases. | Community clean-up campaigns especially rubbish dumps.<br>Seminar on health and nutrition. |
| Use of fine mesh nets by 26 % of the respondents. | Illegal fishing | Knowledge about the proper utilization of natural resources (conservation).<br>Knowledge about the ill-effects of illegal methods of fishing. | Demonstration of fish preservation.<br>Introduction of fish farming (putting up a fish pen).<br>Maintenance of fish pen. |
| Twenty-four toilets in a community of 232 families | Lack of sanitary waste disposal | Awareness of the need to dispose of human waste in a sanitary way.<br>Knowledge about micro-organisms/parasites causing infectious diseases and parasitism in the population. | Seminar and demostration on the construction and use of water-sealed toilets by research and development team.<br>Encouragement of the use of services from rural health unit personnel (local) |
| Non-availability of a doctor | Inaccessibility of medical service/ health care | Awareness about need to select the right people for health services.<br>Knowledge about the use of medicinal plants for simple ailments. | Seminar on health education and proper care of sick children (with the help of local consultants from the Ministry of Health and Ministry of Education and Culture). |

TABLE 1 — *continued*

| Data | Problems | Implications for curriculum | Implications for non-formal education (adults) |
|---|---|---|---|
| | | Need to maintain a medicinal plant garden at school.<br>Awareness about the difficulty of getting proper health care: need to keep oneself healthy. | |
| Soil analysis showed only a few kinds of plants can grow.<br>Low-fertility soil, according to soil analysis results. | Limited vegetable supply and hence no or limited amount of vegetables in the diet resulting in unbalanced meals and poor nutrition. | Awareness about the need for balanced meals for proper nutrition.<br>Knowledge about the importance of vegetables in the diet and good nutrition.<br>Awareness about the kinds of plants available in the area: alugbati, kadyos, etc. | Seminar with mothers on the preparation of locally available nutritious foods.<br>Community campaign on vegetable gardening in trenches and used containers (plastic, bamboo rafts, or pots).<br>Malunggay tree-planting project (a fast growing tree, the leaves of which serve as a vegetable). |

fish-nets, maintaining and repairing pump-boat engines, making watersealed toilets, constructing a solar still, salting and smoking fish, preparing balanced meals and making and maintaining organic rubbish pits.

ISMED also facilitated the establishment of a co-operative, a reading centre, a medicinal garden and a sewing circle for mothers.

Instructional materials focusing on the health aspects of drinking-water sources, sewage disposal and food contamination, among other topics, were produced. These were introduced in the primary-school health and science classes.

## Science and technology education and livelihood

ISMED has also attempted to link science and technology education with livelihood activities as in the recently concluded Unesco sponsored project on the development of exemplary 'Science for All' teaching/learning units for primary-school science. The project was addressed to the needs of pupils who may drop out of school prematurely. Its main aim was to equip pupils with so-called livelihood skills to prepare them for work.

With the help of experts from the academic and the agrotechnological sectors and of science curriculum writers, ISMED drew up a list of livelihood-related science skills. These skills were: observing; comparing; classifying; inferring; counting; measuring; estimating; recording; analysing/evaluating; reporting; doing/using/handling (manual processes); operating/manipulating (tools and machines); banking/accounting; and selling/marketing products.

Primary-school science pupils and teachers were involved in the development of exemplary livelihood activity-based teaching/learning units. The teachers selected indigenous technologies in their communities which would best provide opportunities for pupils to learn basic science principles and to develop positive work-related attitudes and values.

These teaching/learning units were based on the following indigenous livelihood-related technologies: making *balaw-balaw* (shrimp fermented in salt and cooked rice), processing papaya fruit (pickling and candy-making) and vegetable farming.

Efforts were made to ensure that pupils would gain the maximum benefit from their experiences. They were taught how to conduct interviews to get information from their 'resource persons' such as a farmer or a local *balaw-balaw* maker. They were instructed in the conduct of a market survey, and the making of a simple profitability analysis of their activity and of estimates of large-scale production costs. They were also informed about where to borrow capital should they want to engage in small business.

## STEPS modules

As part of its commitment to disseminate relevant science and technology information to primary- and high-school students, the Institute developed several STEPS (Science and Technology Education for Philippine Society) modules. Among these modules were the following:

*Water in Your Community*. This module focuses on groundwater as a source of drinking water for many communities. It presents concepts on how water is brought from the ground to the homes and how precious water resources may be lost if the call for water conservation remains unheeded.

*Plastic, Fantastic?* This module contains information about the technology associated with plastic bags. It also includes activities that investigate the properties of this ubiquitous material and some suggestions and reasons for recycling plastic bags.

*Goodbye Waste.* This learning module presents a way of minimizing waste-disposal problems through recycling. It suggests presorting waste according to the 'five Fs'—factory materials, future-use materials, fuel, feeds and fertilizers—thereby encouraging maximum utilization of materials otherwise thrown away or wasted. The module presents a detailed discussion on converting waste into organic fertilizer (compost) including the procedure and science ideas involved. Built into the module is the development of positive attitudes towards the merits of recycling.

*Preparation of Fish and Shrimp Bagoong.* This module describes a procedure for preserving fish and shrimp by fermentation. It includes some scientific concepts and principles underlying the technology of fish fermentation.

*Go Nuclear?* This module, written in dialogue form, aims to give some facts and explain some issues and science concepts associated with a nuclear energy plant. Particularly, it discusses the plant's construction; the production of electricity; the nuclear reactions involved; the means of control over the nuclear reaction; the benefits of having the plant; comparison of costs and dangers of the plant with those of an oil- or coal-fired plant; and the effects of a nuclear plant on the economic situation and relationships with foreign groups.

*Borrowing Money.* This module presents some borrowing schemes including personal lenders and credit unions. Each scheme is discussed in detail. Examples and exercise sets are included to help the reader understand the effects of borrowing money on both the lender and the borrower.

Other titles included in the STEPS project are: *From Rocks to Cement*; *Trap the Energy of the Sun*; *Lye from Wood Ash*; *Making Your Own Hollow Blocks*; *Laundry Soap from Waste Cooking Oil*; *Nuclear Power: Pros and Cons*; *Solar Cooking*; *Plastics in Our Lives*; *Table Salt from Seawater*; *Water and Health*; *Vitamins and Health*; and *Electrical Energy Conservation at Home*.

## The Science Education Development Plan for the Philippines

Realizing the need to reduce the 'disparity between the goals of science education and the real needs of the society' the science education sector, led by the National Science and Technology Authority (NSTA) and the Ministry of Education, Culture and Sports (MECS) in collaboration with representatives from higher education, industry, mass media and professional organizations from many parts of the country, evolved a science education plan for the Philippines (MECS/NSTA, 1983, 1985*a*, 1985*b*).

The plan defined policies and implementation guidelines covering the following matters: organization, finance, curriculum, staff development and welfare, textbooks and instructional materials, equipment and facilities, research and linkages.

The major goals and thrusts of science, mathematics and technology education as set forth in the Science Education Development Plan are designed to contribute to the country's development goals and are expressed as follows.

First, to gear science education to meet the present and future manpower requirements of the government's long-term thrusts, including:

Self-sufficiency and countryside development.

Balanced agro-industrial development: improved productivity in agriculture, forestry and fisheries, selective import substitution; increased modernity and export development.

Development of skills related to industry: food processing, electrical and electronics, textile and garment, wood and wood-based, chemical, mining and mineral-based, iron and steel, rubber and leather industries.

Development of knowledge and skills related to energy systems, e.g. agriwastes, application of gasification technology, charcoal, dendrothermal, alcogas, solar and wind energy, coal resources, geothermal resources, energy conservation and energy information system.

Strengthening and sustained development of the basic sciences and emerging technologies.

Emphasis on health and nutrition under three major research programme areas: biotechnical research and development, pharmaceutical research and development, and health services research and development.

Second, to provide Filipinos with basic knowledge and tools in science and technology for creating and enjoying high standards of living.

Third, to create an awareness of science and technology in everyday life.

Finally, to improve the pre-service and in-service education of science and mathematics teachers at all levels, and to provide incentives for the best students to enter the teaching profession and to make their careers in it.

The curriculum-related policies and implementation guidelines for the first two levels of education are as follows:

To design more relevant curricula for the first two levels of education with emphasis on science that is more meaningful to the lives of the students and their environment, and that will make them receptive to scientific ideas and science careers. Include new thrusts and developments, such as food production and processing, environmental protection and preservation, water-resource development and management, health and sanitation and other basic human concerns.

To incorporate community-based science education for the first two levels of education, which will make the curriculum more responsive to community/regional needs and more geared towards increasing productivity, for example, using indigenous materials, addressing local problems, adapting appropriate technology.

To devote increased time to the teaching of science, mathematics and technology at the first two levels of education.

The elementary school mathematics curriculum should aim mainly at mastery of the four fundamental operations with whole numbers, fractions and decimals; a thorough understanding of these arithmetic operations; knowledge of when each should be used; and skill in informal mental arithmetic, estimation and approximation. Informal geometry concepts and some beginnings of algebra can also be introduced at this level.

To focus science at the elementary level on basic science concepts that relate to practical real-life situations and on skills that the students can use to meet problems in health, sanitation, conservation, food production, nutrition and similar concerns. However, the spirit of wonder and curiosity about natural phenomena and things around them so easily aroused in young pupils should be stimulated and encouraged. Development of cognitive skills appropriate for this level should also be sought in the context of science topics.

## Planning a science and technology education programme for primary-school children

As stated earlier in this chapter, for many children in the developing countries, primary education is their first and last formal education. Many of these children are from peasant farming families living in remote settlements who survive by subsistence agriculture and fishing. Others are children from urban families living in deplorable slum conditions. Of the children attending school in such areas, a considerable number leave before completing Grade 4. Most grow up to be impoverished and unemployed adults.

These factors should be taken into account in developing a science and technology education programme for primary-school children. If this is to be relevant and functional, it should prepare children for life and work; it should focus not only on basic concepts that relate to the pupil's real-life situations and on intellectual skills that pupils can use to solve problems related to health and nutrition, sanitation and environmental concerns, but also on practical and basic technical skills needed for productive work. It is not enough, for instance, for the son of a farmer to know about the structure and function of the different parts of a rice plant and be able to design an experiment to find out how much sunlight is good for a particular plant; he should also be able to apply fertilizer, spray insecticide and use a scythe to harvest rice. It is not enough for the daughter of a woman who tends a small fish stall in the village market to know about the digestive and reproductive processes of fish and be able to enumerate similarities and differences between different varieties of fish; she should also be able to prepare fish for cooking and use a variety of methods for preserving fish.

Topics for such a programme can be drawn from expressed and perceived community needs. ISMED has identified the following broad topics in several of its projects:

*Health, personal/family:* pre-natal care; infant care; nutrition (based on local foods mainly); dental care; first aid; use of medicinal plants; and sanitary toilet habits.

*Sanitation of the environment:* rubbish disposal; drainage; eradication of breeding places for flies and mosquitoes; and ensuring safe water supply.

*Environmental pollution:* water pollution (including sea and beaches); pollution caused by man and animals; and air pollution (as in charcoal making).

*Community welfare:* providing water supply; purification of drinking water; and conservation problems such as deforestation and overfishing.

*Economic welfare:* need for co-operatives among farmers and fishermen; alternative economic activities for seasons of low productivity; improving indigenous technology, e.g. better ways of making charcoal, making better fish nets, constructing fish pens, using forest products, etc., using alternative economic activities; and improving food production, e.g. scientific farming, utilizing coves and inland water for raising fish.

*Food preservation:* improving indigenous ways of food preservation; and 'borrowing' successful ways of doing things from other communites.

*Cultural welfare:* providing and developing reading materials suitable for the community's natural and social environment.

All these have important implications for pre-service and in-service teachertraining. New competencies are needed for teachers to be able to link science with the problems of everyday life, to use the resources of the community and local expertise as well. Training courses have to be designed so as to prepare teachers for teaching in rural and in deprived urban communities.

## Summary

The pervasiveness of science and technology in modern life is undebatable. Traces of science and technology are seen not only in the towns and cities but also in the rural farms and *barrios*.

Undoubtedly, science and technology are the most powerful forces in today's world as mankind continues to search not only for a better and richer quality of life but also, unfortunately in some countries, for more powerful means of national aggression. The trend towards a highly specialized and technological society is irreversible.

However, while science and technology continue to take quantum leaps forward for purposes of peace or war in the developed world, much of the Third World continues to exist with the backward traditional lifestyles of illiterate peasant societies. Only a very small minority in these poor countries enjoy any sense of literacy in science and technology.

Yet these areas of the world are in dire need of the basics of scientific and technological knowledge. The rational and systematic approach of science, as ISMED's San Salvador project has shown, can serve as a cornerstone for the progress even of marginalized communities. Science and technology can improve on traditional ways of carrying out economic or life-sustaining activities. Science and technology can also bring new possibilities for livelihood and offer the best prospect for an improved community life *in toto*.

For these reasons, it is important to realize that science education is not an option but an imperative in the modern world, especially for poor societies. Not to give it priority in an increasingly technological world is to drift towards national oblivion, perhaps even social extinction.

It is vitally important to design a programme of science education based on recognized needs, economic realities and the socio-cultural milieu of the society. These points serve as the springboard for the formulation of a relevant, interesting and effective curriculum. For pupils, students, out-of-school youth and illiterate adults, a science curriculum related to their everyday life and their real world provides the best motivation for, and best meaning of, science learning.

## References

HARLEN, W. (ed.). 1983. *New Trends in Primary School Science Education*. Vol. 1. Paris, Unesco. (The Teaching of Basic Sciences.)

HERNANDEZ, D.F. 1978. A Philippine Scenario for Lifelong Education: Its Operation in a Fishing Village. *Innotech Journal* (Quezon City), Vol. 2, No. 2, pp. 12–22.

——. 1980*a*. Biological Education and Development in Rural Communities of a Developing Country. In: P.J. Kelly and G. Schaefer (eds). *Biological Education for Community Development*, pp. 89–96, 180–2. London, Taylor & Francis.

——. 1980*b*. Biology in Community Education: A Philippine Scenario for Lifelong Education. *European Journal of Science Education*, Vol. 2, No. 3, pp. 217–30.

——. 1982. Patterns of Relevant Education for Countryside Development. *Innotech Journal* (Quezon City), Vol. 6, No. 1, pp. 6–19.

MECS/NSTA (MINISTRY OF EDUCATION, CULTURE AND SPORTS; NATIONAL SCIENCE AND TECHNOLOGY AUTHORITY). 1983. *The Context of Science Education*. Quezon City. (Prepared and published for the Science Education Development.)

——. 1985*a*. *Science Education Development Plan*. Vol. 1: *Source Materials*. Quezon City.

——. 1985*b*. *Science Education Development Plan*. Vol. 2: *Plan of Action*. Quezon City.

a Developing Country, In: P. J. Kelly and G. Schaefer (eds), *Biological Education for Community Development*, pp. 89–95, 110–2, London, Taylor & Francis.

—— 1980. Biology in Community Education. A Philippine Scenario (in Lifelong Education. *European Journal of Science Education*, Vol. 2, No. 3, pp. 217–30.

—— 1982. Patterns of Relevant Education for Community Development. *Education Journal* (Quezon City) Vol. 9, No. 1, pp. 46–48.

PHILIPPINES. MINISTRY OF EDUCATION, CULTURE AND SPORTS; NATIONAL SCIENCE AND TECHNOLOGY AUTHORITY. 1984. *The Content of Science Education*. Quezon City. (Prepared and published for the Science Education Development [illegible].)

—— 1985. *Science Education Development Plan*, Vol. 1: [illegible]. Quezon City.

—— 1985. *Science Education Development Plan*, Vol. 2: *Plan of Action*. Quezon City.

# Science and technology education for the world of tomorrow

Charles Taylor

## Introduction: the world of tomorrow

This chapter is, of necessity, somewhat speculative, partly because it deals with problems that will arise in the future, and partly because I am, by profession, a university physicist who happens to be interested in science and technology education at all levels, rather than a specialist in education. It must also, of necessity, present a very personal view.

When I was a small boy my grandfather's house was lit by candles and oil lamps and our own house was lit by gas. I can still remember the impact that electric light made on me when, at the age of 4, the family moved to a new house. But consider the development of lighting through the years; the intervals between the successive steps in development from the first oil lamps, 20,000 years ago, to the laser, twenty-five years ago, have decreased with amazing rapidity. We could have chosen any one of many other fields such as transport, communications and medical treatment and in each case we would have found the same exponential acceleration in the development of new techniques and devices.

When I was young it was reasonable to choose a career and then work towards it in the expectation that a job would still be available in it after completing the necessary training; now I find it difficult to advise students who ask me which branch of physics will be fashionable when they graduate in three years' time!

So, the first point I want to make about the world of tomorrow is that there will be far less stability and people may well have to change direction in their careers several times simply because of the rate at which new developments occur. This will obviously have a considerable influence on the way in which science and technology education has to be rethought. 'Education for change' is a useful key phrase.

The second point is that there will be an increasing amount of leisure time as various new technologies enable machines to do the boring, repetitive, or dangerous jobs. And this will apply equally to the developing countries where, though starting further back, the pace of development may be even more rapid. This means that a great many more people will be able to indulge in the luxury, or perhaps we should say be in a position to exercise the basic human right, of having time to think. So public awareness of science and technology will assume even greater importance; scientists and technologists will need to be able to relate their disciplines to other aspects of their cultural environment. Perhaps 'Education for awareness' could be our second useful key phrase.

The third point that I consider significant is that transport and communications are developing at such a pace that, effectively, the world is shrinking, and if we are not careful a dreadful uniformity may arise. We are making great efforts now to preserve the biological environment so that we do not precipitate irreversible changes in habitats, weather patterns, natural resources, etc. I believe that similar efforts will be needed to preserve the cultural environment of different countries and regions, and this again means that science and technology education must relate to the locality as well as to the world. 'Education for individuality' is my third choice of key phrase.

Finally, though I am sure many other points could be made, just as when we view science education on a world scale we must ensure that local cultures are preserved, so we must be prepared to move in the other direction, into outer space. There are still many problems to be solved before space travel becomes a reality for all; but, if we compare the fifteenth-century European view of exploration of the world with modern jet travel, and allow a factor of ten for the speed up in technological development already mentioned, then, in fifty years' time, week-ends on the moon may be a reality. Whether or not this is the case, our children must be enabled to understand the problems and assess the priorities, and possibly be prepared to make decisions about setting up large communities elsewhere in the universe. 'Education for adventure' is probably the best encapsulation of that element in the programme.

## Attitudes to science and technology

Although science can be a very exciting topic and many children take an enormous interest in it at school, there can also be a strong negative reaction. Resources at school are usually fairly limited and so it often happens that children's only real experience of sophisticated science and technology comes through television and films. All too often this is related to science fiction, nuclear, chemical or germ warfare, or to devices used to fight, or further, crime as for example, in the James Bond type of film. Scientists are usually portrayed as either criminal, insane or so single-minded as to be completely inhuman. I suppose that this is particularly true of the developed world, but it is certainly not unknown in less developed countries.

Science and technology tend to be equated with pollution, the destruction of the environment and exploitation of all kinds.

These attitudes are reinforced by parents who often have an even less balanced view of the positive contributions to human welfare that are made by science and technology than do children. The advent of 'new technology' has further adverse influences. Many parents have been made redundant or have had to retrain through the introduction of new technology and there are many examples of opposition from organized labour. Parents and grandparents can pass on their very real fears of science and technology, especially in tightly knit village communities. I recall an instance of people in a community who still walked five miles to collect water even though a pipeline existed. The problem was that on its way downhill the water drove an electric generator which, it was feared, extracted 'vital power' from the water and made it unfit either for drinking or for irrigation.

In the United Kingdom recently there has been a worrying decline in the number of physics teachers in school to such an extent that several crisis meetings have been held to try to rectify the situation. One important element in the discussions has been the engineering professions' need to have physics taught well at school. The basic subjects taught at school at present as a preparation for the scientific or technological elements in a career are mathematics, physics and chemistry; all these tend to be presented by teachers as difficult subjects, and only the brighter pupils are encouraged to study them. As a consequence, many pupils who could benefit greatly from at least a basic knowledge of science shy away from it. Frequently, when people ask me what I do and the fact that I am a physicist emerges, they tell me that physics has always been a closed book to them and that it is no use my trying to explain what I do because they would never be able to understand. In other words, they have a mental block that has been set up by the general attitudes of teachers, parents and friends. Clearly science and technology education for the world of tomorrow must somehow avoid creating this kind of block by removing some of the mystique and presenting science as a way of looking at the world around us that can be accessible to all, and by explaining the positive contributions of science and technology to the needs and well-being of the people of the world.

## Why do we still need science and technology education?

The Committee on the Teaching of Science (CTS) of the International Council of Scientific Unions (ICSU) prepared a paper justifying science education as an important element in development, as an input to the United Nations Conference on Science and Technology for Development in 1979. The following extract from this paper (CTS, 1979, p. 10) seems to me to be a good starting point in trying to answer the question of why science and technology education is still important:

> It is our opinion that the healthy growth of science and technology in any country depends critically on the availability of technically and scientifically trained manpower and that it is the responsibility of the indigenous educational system to provide such manpower.
>
> Furthermore, we would maintain that the successful exploitation and assimilation of scientific and technical development can only proceed with the support of an interested and informed public. The responsibility for fostering this interest, and for ensuring that the public is properly informed rests clearly with the educational system of the country concerned. Any policy that fails to recognize the importance of these two factors can, at best, produce only short term improvements; at worst the country concerned could experience serious failures in technological development.

An important element in this statement is the stress on the need for public understanding in addition to the more obvious requirement of supplying scientists and technologists to continue development and to run the increasing proportion of highly technical systems in society. Clearly science and technology have such an enormous impact on all aspects of our lives that it is becoming impossible to exercise our democratic rights to vote either locally or nationally without understanding something of the scientific aspects of particular programmes. Science impinges on the nuclear debate, and the environment debate, as well as on many other political issues. Science and technology are just as much part of our cultural heritage as literature, art and music; if we regard education generally as a 'good thing', they should therefore form an element in everyone's education.

In order to achieve these goals we must have teachers who are trained to place science and technology in the proper context; and the next generation of teachers will be drawn from those who are making a more specialized study of science at school and therefore this reservoir of talent must be increased. But, between those who need a little science and those who will become specialists there are others who, in my view, should be receiving more background in science. I am thinking particularly of administrators and politicians who make all kinds of decisions affecting our future and yet who are often woefully ignorant of the technical aspects of the matters on which vital choices depend. Obviously they have expert advisers, but without some background it is very difficult to appreciate and evaluate expert advice. Most politicians know enough about financial or legal matters to judge, for example, what weight to place on different forecasts or opinions, and, indeed, to know which experts they should consult. Regrettably this is rarely true of science and technology.

## Tradition dies hard

There will always be arguments about the precise topics that should be taught in order to inculcate positive attitudes to science and technology. In the United Kingdom, and I suspect it is also true elsewhere, the normal inertia that prevents change—the cost of new books and equipment, the work involved in preparing new materials, the cost in time, effort and money of retraining teachers etc.—are compounded by an examination system that effectively determines what is taught. It is now thirty years since the Physical Science Study Committee at the Massachusetts Institute of Technology (MIT) began its revolutionary new approach to science teaching that triggered off a whole series of new curricula. In spite of this, there are still physics teachers who would like to stick to the age-old divisions of physics into heat, light, sound, electricity and magnetism, mechanics and properties of matter, and I am sure the same conservatism occurs in other branches of science and engineering. There is inevitably a time lag because, unfortunately, all teachers are not prepared to depart from what they were taught as students and, generally speaking, the only reward for the exceptional teacher who wants to break out of tradition is a sense of satisfaction. There is thus a kind of vicious circle that keeps the traditions going. How can we break out of it? In a paper prepared for the Ljubljana conference on teaching and popularizing science and technology as aids to development I wrote (Taylor, 1984, pp. 141–2):

> The attitudes of the public at large are determined by first introductions to science at a very early age; these attitudes can be disturbed by prejudice and traditions in the home. Teaching in universities influences teachers at school; and good practical teaching and research in a university depends on a supply of trained technicians. This, in turn, depends on good technical teaching, but even more so on the development of positive attitudes towards careers in science and technology. So we see how convoluted the processes are. The only hope of breaking the circle is a simultaneous attack at all levels.

## Starting to meet the new demands

Adapting our science and technology education in order to break into the circle and to meet the four challenges of education for change, awareness, individuality and adventure is obviously a tall order. So where do we start?

I am certain that we need to look hard at the way science is first introduced to children and to start at the very earliest age. There is no reason why even 3-year-olds should not come in contact with simple scientific ideas at play-school. After all they experience poetry, literature, music and art through their nursery rhymes, stories, songs and painting, all of which are presented as a natural part of life. Science is really just asking questions about the world around us, and what child does not ask questions? So why not stories or verses about children asking questions and finding out things for themselves? In primary school there are abundant possibilities. One of the big problems seems to me to be that teachers tend to be afraid of science. They are quite happy to tell stories without having a degree in literature, to teach simple songs without a degree in music, to supervise children drawing and painting without a degree in art. Why then be scared of science? I believe that one of the major obstacles is the attitude of scientists themselves.

Scientists, perhaps unconsciously, have tried to keep their knowledge confined to the initiated: magicians have the Magic Circle; doctors have their medical association which determine who can practise; and scientists become very worried if untrained teachers teach science. They speak about the problems of unlearning incorrect science at a later stage. But in my view it is vitally important that children should be exposed to scientific ways of looking at things, of doing simple experiments, and of asking questions, even if some of the answers are oversimplified or even wrong. It is the attitude and open-mindedness of approach that matters.

A mistake that I think science teachers at the secondary-school level have made in the past, and one that tends to create mental blocks in those of less ability and interest, is to teach in a very dogmatic way. I remember that, even though I had an excellent and inspiring physics teacher, we were taught a great many 'absolute truths' and the notion that any departure from these was scientific heresy was certainly implied. If that method is still employed, and I know that, regrettably, it is still all too common, it is not surprising that teachers are worried that 'wrong science' will later have to be unlearned. If the teaching is less dogmatic, then the occurrence of a few errors in the teaching will have much less impact, and more precise ideas can be introduced as a development from the early incorrect notions; indeed, such a sequence could have positive advantages in giving the children vital experience in realizing that adults—even experts—do not always know everything!

So one of my contentions is that science should be introduced as early as possible; it does not matter if the teacher is unqualified in science long as there is enthusiasm for scientific inquiry. Science at this level should not be taught in a special room by a special teacher, implying already the notion that it is totally different from the rest of life; children should be unaware of any 'change of gear' when the topic changes from stories, painting, or singing to science.

Then, when science is treated a little more seriously at the secondary-school level, there should be less emphasis on dogmatic 'correct' science; of course, many of the less traditional courses (for example the Nuffield courses in the United Kingdom) are already doing this, but, as the title of the previous section asserts, tradition dies hard.

The emphasis I have placed on attitudes rather than on learning about rules, definitions and laws is important at all levels in a climate of change. No scientist these days can be expert in every branch of the subject even just after graduation and if he concentrates on a particular technique for his postgraduate work he may well find that, by the time he is looking for a post-doctoral appointment, it has been supplanted by something quite different. It is much more important that he should have been trained to think, to adapt and to improvise in a scientific way than that he should be exhaustively familiar with any one narrow field.

## What then should be taught?

Many new courses have been introduced at universities in recent years. Communication studies, informatics, science studies, computing, electronics, environmental science, etc., are all attempts to break away from the old labels and to combine basic topics in a way that should be more relevant to the problems facing the world. The great difficulty that most of them have come up against is that fashion changes very rapidly and what may be popular for a year or two then becomes old hat. A solution that some universities have tried with some success is to retain the old departmental divisions of physics, chemistry, biochemistry, zoology, etc., and to group courses provided by these departments in different ways either on a course-unit system (sometimes called the 'cafeteria' system, since students choose more or less freely from a menu), or on a package system, but in which the contents of the package can be changed from year to year to suit changes in demand. Perhaps some of these lessons can be transferred to school.

New subjects are now being introduced at school level. Informatics, computing science, engineering science and design technology are typical examples. I may be accused of being old fashioned, but I do have reservations about some of these. I think part of my doubt lies in my fear that the inertia to which I have already referred may lead to these subjects being retained in the curriculum beyond their useful life; and part is due to the fact that I cannot help feeling that the basic style of thinking and approach to scientific and technical problems that is taught under the umbrellas of physics, chemistry and biology still provides a better basis for those who will face the exciting and rapid changes of tomorrow's world. Obviously the teaching techniques need to be changed to bring out the innate excitement of the subjects and to show how closely science is tied up with everyday life; the examples need to be constantly updated and made more relevant to current problems; and the actual topics taught need to be changed from time to time. As the head of a university department of physics I was much more concerned with the enthusiasm and attitudes of my incoming students than with the precise topics they had covered at school. In any case, as was pointed out in a paper by the Royal Society (1975, p. 6):

> In practice, there are at least three versions of a syllabus which, in order of decreasing size, are: the official printed list of topics, the teacher's interpretation of it, and the topics actually learned by a given student. Regrettably, of course, the latter version is not available to us!

I am certainly in favour of a broader syllabus than has been common in the later years of secondary-school education in the United Kingdom, and indeed the new examination system just being introduced will help in this direction. But whatever the choice of subjects and labels for courses, one of the overriding needs in my view is to break down the barriers between disciplines. An obvious example, on which a good deal of conference time has been spent, is the maths/science interface. There are schools in which physics and chemistry teachers use traditional mathematical notation and mathematics teachers use 'new' mathematics, and yet they never discuss with each other the problems this presents to their pupils. Another example is physical science, combined science, or completely integrated science; if pupils are to cover a wider range of topics, is it justified to make more space in the timetable by combining physics and chemistry, or even all the sciences? Within limits I am happy with this type of combination, provided that the subject is taught with real enthusiasm.

What about informatics? Obviously communication is one of the most significant factors in the modern world, computer technology is transforming the world of work, and the information explosion is reaching such a level that serious consideration will soon have to be given to at least supplementing books and journals with electronic storage systems on a much wider scale than at present. But again we face the problem of rapid change. It is not very long since it was being predicted that microfilms and microfiches would form the basis of libraries of the future; in a surprisingly short time these have been overtaken by electronic storage-and-retrieval techniques. My instinct is that it is much more important to teach children to be *aware* of the problems of information storage and transfer rather than to overburden them with specific present-day solutions that may well be obsolete before they reach maturity.

## Teaching aids

There has been much talk recently of the expense of providing enough apparatus to enable all students to have actual hands-on experience in laboratories. If the suggestion is to replace this by computer simulations then I disapprove. Simulations, of course, fulfil a valuable complementary function in enabling students to test for themselves the effects of changing parameters in a large-scale experiment that would be far too costly, or even too dangerous, to set up in reality. But I do think it is important that all pupils, whether destined for careers in science or not, should be given the opportunity to perform experiments themselves. The difficulty is that, although we now place great theoretical stress on experiment, demonstration and other visual processes as aids to learning, lack of money, technicians and time make it difficult to put all this into practice in many school situations. What alternatives are there? Carefully prepared slides and video-tapes can be used very effectively but they in turn raise problems. Mark Boulton (1987) of the International Centre for Conservation Education warns that the use of slides does not automatically make any talk more interesting. It is often most effective if slides are used as a background to a talk that is already interesting in its own right even without the pictures. The real problem about video presentations is who is to make them. A producer who does not understand the subject may end up with a very professional presentation that completely misses the point. On the other hand there are not many science teachers who are sufficiently familiar with the technical aspects of production to make a worthwhile programme. Some professional bodies (for example the Institute of Physics in the United Kingdom) are beginning to make video presentations in which someone skilled in presenting a science topic is teamed up with a professional television crew to produce programmes that can be used either whole or in part to back up lessons. This may be at least a partial solution both to production and cost problems.

I have already mentioned computer simulation and it is obviously important to mention other uses of the microcomputer in the classroom. So far I think the biggest problem in the effective use of the microcomputer in teaching has been the availability of suitable software; we meet a similar problem to that of video production—that of finding teachers who are sufficiently skilled in the subject being taught and in the art of using the properties of the micro effectively, as well as having the necessary programming skill to produce efficient software. But this will no doubt change with time and Tom Stonier (1987), in a paper written for the Bangalore conference on Science and Technology Education and Future Human Needs, forecasts that 'the emergence of computer-based education will, over the next two decades, have an impact as profound on Western Society as did the establishment of mass education in the late nineteenth century'.

He points out that one of the great advantages of computer-assisted learning is that the computer has infinite patience. He cites the instance of a Canadian girl taking part in an early trial who said that the computer was the first mathematics teacher who had never yelled at her!

The interactive videodisc system has exciting possibilities in using a mixture of computer-assisted learning with rapid access to pictures or video presentations by way of illustration. But it is still an expensive option and I suspect may well qualify as a solution in search of a problem for a year or two yet.

## Experiments in informal education

If we are to change the image of science and to encourage a more integrated approach to science with other school subjects it is clear that merely rethinking classroom practices will not be enough. I should like to mention one or two experiments in less formal methods of education that may be significant. The first is the development of interactive science centres where children (and inquiring adults) can try out experiments for themselves. I suppose one of the earliest of these, started over a century ago, was the Science Museum in London. I remember as a teenager on my first visit the combination of delight at seeing a museum exhibit that could be made to work by pressing a button or turning a handle and frustration at not being able to alter any of the conditions in order to make it do something different! Modern interactive centres such as the Exploratorium in San Francisco, the Questacon in Canberra and many others allow much more interaction and intervention on the part of the visitors. I have had some involvement with two of the most recent centres under development, the Exploratory in Bristol and Techniquest in Cardiff. In pilot runs I have been delighted at the enthusiasm of the young experimenters and came across a side benefit that I had not expected, but which could be enormously valuable in changing the attitudes of grown-ups: quite young children (from 7 to 11 years) returned for a second visit bringing parents and proudly went round explaining the mysteries in an extraordinarily effective way.

About thirteen years ago my former college at Cardiff opened its new university theatre—the Sherman Theatre—and a few colleagues and I felt that it would be unfortunate if this new facility served only the arts departments. We therefore happily agreed to a suggestion by the theatre director that we should set up a Science Week. Lectures and demonstrations on many different scientific topics for both children and adults are presented and many thousands of people pass through during the week. All the lecturers and demonstrators are encouraged to use the full facilities of the stage, including the lighting and sound systems, so that many of the presentations become dramatic spectacles as well as scientific lectures. The Week is now firmly established and occurs every second year. There are many other examples of similar functions (for example in China, Singapore and the Netherlands) and their popularity, especially with the younger age groups (7 to 11) means that it is often difficult to fit in all those who wish to attend, even after repeating events several times.

Earlier in this chapter, I mentioned the need to set science and technology education in the context of the general cultural heritage. One way of achieving this arose as an off-shoot of our Science Week; it was the establishment of a Science, Technology and Drama Competition, which was the brainchild of my colleague John Beetlestone (Beetlestone and Taylor, 1982). For this, schools write and present a dramatic event of some kind, lasting about twenty minutes, on a scientific or technological theme. It may take one of a number of forms including a play, a mime, a ballet or a musical, and the scientific element may be history, biography or exposition of a scientific principle. Judges travel round the schools to witness the performances and the best two under 11 years and the best two over 11 are invited to perform in the Sherman Theatre. There are various rules limiting expenditure on items such as costumes and props. Last year the British Association for the Advancement of Science became interested and similar competitions were set up in different regions of the country, a national final was held at which the five regional winners competed.

These activities are time-consuming and cannot be set up cheaply. Fortunately, a number of far-sighted industrial and commercial companies and trusts have donated financial help and the load is spread by involving a great many people in the enterprises. Quite apart from the value to the children in widening their horizons and perhaps changing their attitudes to science and technology, it is quite clear that all the teachers and students involved in running the events learn a great deal in the process. I have certainly gained enormously in my understanding of how to present science to young people as a result of my involvement.

## Conclusion

Experience tells me that there is no magic solution to the problems we have been discussing. There is no curriculum change, no rearrangement of topics or titles, no sophisticated computer-based learning system, that will suddenly start educating our children for change, awareness, individuality and adventure. I have written of the problem of breaking into the vicious circle, about new approaches, new teaching aids, etc., but in the end it all depends on the people who put the new notions into practice. In their splendid book on *Visual Communication in Science*, Barlex and Carré (1985), after commenting on the improvements in response and understanding of students that come when a rather haphazard demonstration is carefully redesigned, say, 'However, the insight to consider the students' view of the scene can only come from the teacher.'

So the most significant conclusion that I can reach is that it is the training of teachers to adapt to the new situations that are arising that will probably have the most important contribution to make to our future; not only are radically new approaches to basic training needed, but also more or less continuous in-service training; in the end this means that greater numbers of teachers are needed in order to give time and opportunity for this retraining and to enable them to make better use of the modern aids that are available. Somehow we must find a way to restore the dignity and desirability of teaching science and technology so that enthusiastic young people will see it as a rewarding career. Then the four challenges of education for change, awareness, individuality and adventure will be able to be met.

## References

Barlex, D.; Carre, C. 1985. *Visual Communication in Science*. Cambridge, Cambridge University Press.

Beetlestone, J.; Taylor, C.A. 1982. Linking Science and Drama at School. *Impact of Science on Society* (Unesco), Vol. 32, No. 4, pp.473–80.

Boulton, M. 1987. Audio-visual Techniques for Conservation. In: C. Taylor (ed.), *Science Education and Information Transfer*, pp. 51–7. Oxford, Pergamon Press.

CTS (Committee on the teaching of science of the international council of scientific unions). 1979. *UN Conference on Science and Technology for Development*, pp. 10–15 (Newsletter, No. 3.)

Royal Society. 1975. *Entry to Physics Courses at the Tertiary Level-* London, The Royal Society.

Stonier, T. 1987. Computers and the Future of Education. In: C. Taylor (ed.), *Science Education and Information Transfer*, pp. 210–13. Oxford, Pergamon Press.

Taylor, C.A. 1984. Life-long Science Education and Its Role in Development. In: A. Kornhauser (ed.), *Teaching and Popularising Science and Technology as Aids to Development*, pp. 134–43. Ljubljana, Yugoslavia, Unesco International Centre for Chemical Studies, Edvard Kardelj University—Ljubljana and the Yugoslav Commission for Unesco.

# Science and technology–educating a wider public

Goéry Delacôte

> *Le rêve est plus fort que l'expérience!*
>
> G. Bachelard

In March 1986, just when the European space probe *Giotto* was nearest to Halley's Comet, the President of France inaugurated the largest complex ever built in France to facilitate access to science and technology for all sections of the public—the Cité des Sciences et de l'Industrie (CSI), which is situated at La Villette, in a park of approximately half-a-mile square under development at the north-eastern extremity of Paris.

An earlier inauguration had taken place on 8 May 1985, however. This was of an unusual building in the form of a steel sphere, separate from the main building. Covered with 6,400 triangular panels of stainless steel, this spherical building has become the symbol of the whole complex. Set above a flat surface of water, it looks from the outside like a spherical mirror reflecting the whole of the surrounding area. It houses a semi-spherical auditorium called the *Géode*, which is unique in France.

Taking in 900,000 spectators on the average, in batches of 350, and plunging them into images and sound emanating from a spherical screen of an area of 1,000 $m^2$—the largest in the world—it has a 15 kW water-cooled Omnimax projector (a Canadian process), which projects 70 mm films horizontally using a fish-eye lens. It is also equipped with a laser projection unit, a battery of film and slide projectors (1 kW and below), a sound-reproduction system consisting of twelve loudspeakers situated at different points in the auditorium, three of which function in the 40–100 Hz waveband for special oscillatory effects. The films screened come from a film library catering for this special kind of auditorium throughout the world; the making of French films thus contributes to international distribution, without which production would be uneconomic. During the first year the auditorium made sufficient profits for a steady recovery of its construction and fitting out.

This spectacle—a veritable advertisement for the Cité—is testimony to the intentions of the Cité's founders, grouped around Maurice Lévy, who conceived the project: its architecture is symbolic (the architect is Adrien Fainsilber, Grand Prix d'Architecture 1986); the technology is visible, the projection room being made of glass; the message is spectacular; and the medium takes us back to the beginnings of cinema—documentaries on space and its conquest, on time, water, the ocean and the planet Earth, precursors to the discovery of the possibilities of such a technology for fiction and dramatization.

## The purposes of the CSI

The three main purposes of the project were: (a) to give recognition to the importance of science in present-day technological and industrial achievements; (b) to facilitate the access of all sections of the public to scientific knowledge; and (c) to illustrate not only the idea of progress but also the associated risks.

It is interesting to compare these purposes with those put forward when another centre far ahead of its time, the Palais de la Découverte, was established in 1937 on the occasion of the International Exhibition of Arts and Techniques in Modern Life.

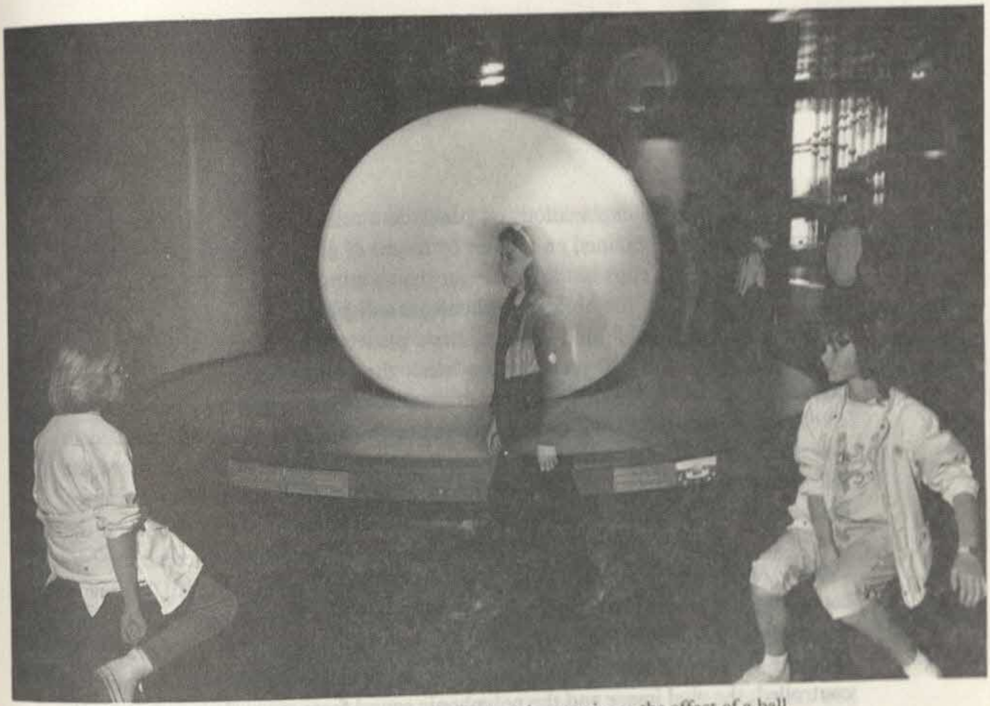
In 1937 it was a question of helping to make the public, and hence the government, aware of the fact that scientific research and discoveries are indispensable prerequisites of all human progress, and at the same time stimulating an interest in scientific vocations among the young people who flocked to see the experiments on display.

At La Villette in 1987 science is no longer regarded in isolation but is viewed in the context of industrial activity and technology. Exhibits are no longer organized in accordance with the disciplines of science to be found in a general encyclopedia but according to themes.

This is particularly evident in the arrangement of the permanent exhibition—*Explora*—centred on man and his relations with the world around him. Designed as a huge open space, with an area of 30,000 m$^2$, distributed over three levels in the main building, *Explora* is divided into four sections with deliberately imprecise boundaries.

The first section, *From Earth to Universe*, shows means of probing space and sounding great depths: the nose-cone of the Ariane rocket, a reconstituted orbital space station, the submersible *Nautile* capable of exploring 97 per cent of the sea-bed.

Dummies simulate explorers of space at work. 'Hands-on' consoles set in a slate wall invite participation in games involving interaction with the visitor and interactive exhibits illustrate the principle of action and reaction etc., arousing curiosity, provoking thought and creating a desire to know more. The policy has



Visitors to the Cité des Sciences et de l'Industrie experience the effect of a ball of carbon dioxide in the World of Sound (Explora, Section IV).

This pupil is getting an eye-opener at the Cité des Sciences et de l'Industrie's 1987 exhibit aimed at proving that truth is stranger than fiction.

*Photos*: Bernard Baudin/Cité des Sciences et de l'Industrie been to reduce verbal explanations on panels to a minimum. On the other hand, information may be obtained on request by means of glossary terminals displaying original audio-visual clips lasting no longer than a minute. These explain concepts needed to understand the objects or phenomena displayed.

This permanent exhibition also includes a planetarium, equipped with swivel-chairs, which enables 270 spectators to break the boundaries of space: *Franchir l'espace* is the title of the first item, an original poem composed by Michel Butor. The spectator embarks on a caravel like the one Christopher Columbus sailed in and goes back into the past. Man unravels the mysteries of the motions of the celestial bodies. He then frees himself from the force of gravitation, travels through the solar system and discovers the fabulous worlds making up our Galaxy and the rest of the universe. The journey is effected under a dome-shaped screen in area, 600 m$^2$. At its centre is a starball 1,200 cm in diameter projecting 10,000 stars, containing ten planet projectors, two sun projectors and a moon projector. Along the periphery a battery of projectors provide for special effects—showers of shooting stars, various panoramas, northern lights and solar eclipses. Computer-controlled, the vital image and the polyphonic sound from space thus penetrate the earth-bound and finite planetarium. Near by is a closed-in area in which the visitor can experience life in a non-Galilean universe where it is impossible to walk straight or throw a ball along the usual trajectories.

The green bridge devoted to hydroponics—plants cultivated *in vitro* without soil—straddles the entrance hall with an area of 6,000 m$^2$. It serves as a hothouse and is an important element in the second section, *The Adventure of Life*. The subsections Human Territories and Living Environments tackle the question of man's mastery of his environment. The story of the French forest is told by means of animation techniques. The main attraction, however, is the 'life-tram'. A cable-car takes three visitors through a succession of small rooms in which multimedia displays present the major themes of human life. The first one presents different points of view—the biologist's, the lawyer's, the historian's—situating death as indissociable from life. Another shows the interior of a brain. Yet another illustrates the role of the HLA system in the rejection of grafts. The last one shows world population trends in the heart of a globe crossed by tens of thousands of optic fibres and demonstrates the operation of a population time chart inspired by Marey. Before leaving this section, the visitor can take a look at the 'secrets of living things' (he selects some part of his body and sees it enlarged and broken down to the cellular level) or again watch, in a cellularium, the first meeting of an ovum and a spermatozöon—a meeting not without consequences.

*Matter and the Work of Man*, the third section, takes the visitor into a fantastic world of robots and technology which needs at least eight hours to visit properly. Transport by containers, the piloting of an A 320 Airbus, the birth of the industrial world, Marx and Keynes, the space vehicle and the Rafale aircraft, energy and matter, and the Shaddocks pumping and repumping until they reinvent the steam engine—these are but a few of its attractions.

The fourth section, *Languages and Communication*, is perhaps the most successful, this display being the most arresting and the most human. Here the visitor finds more familiar landmarks and is constantly confronted with his own image. Daedalus lays bare the operation of artificial intelligence. The computer endowed with speech vies with the human brain. The visitor can even regulate the lighting of a photographer's studio, be introduced to the interpretation of the visual image or reconstitute the barely perceptible movements of his own face recorded in a few seconds by high-speed video.

## Integration of activities centred on communication

This vast effort to bring science within the realm of communication by means of an overall, qualitative, media-like, visual, hands-on approach is not limited to the permanent exhibition area—keystone of the edifice; a great variety of areas and activities are available to the public and the originality of La Villette is probably due to this *integration of activities* affording different gateways to the complex network of scientific knowledge and technical information. Some 100,000 m$^2$ are divided up between a number of activities, including the permanent exhibition.

### *The temporary exhibitions*

In addition to *Explora*, temporary exhibitions allow co-productions with outside organizers on themes in the fields of science, technology, industry and art. Contemporary art and creation are thus very much present in the complex as a whole. Examples of such collaboration are the exhibition, *The Earth that Produces our Food*, co-produced with the powerful agrobusiness sector, and *Fifty Years of Television* organized with communication groups. Approaches differ widely—as with the fashion industry—being human, technological, sociological, aesthetic, forward-looking, and/or historical.

### *The House of Industry and the Enterprise Area*

The presence of industrial firms is not confined to the co-production of temporary exhibitions and the financing of different elements in the permanent exhibition. The House of Industry is a showcase for the most outstanding industrial achievements. The object of this documentation centre with audio-visual facilities is to familiarize the public with enterprise. The visitor finds, for instance, a spectacular mural on 'Enterprise—A Human Adventure', or he can take an audio-visual journey to visit selected enterprises on a route such as Paris to Le Havre or Marseilles to Nice.

Every six months the Enterprise Area highlights a particular economic sector. At La Villette industrial groups have access to the technical resources of the Cité and benefit from the reputation of a place in which science, research and industry maintain close liaison. In return, they make a contribution to the Cité's running expenses, which amounted to about 100 million francs ($16 million) in 1986.

### *The Inventorium*

Special areas have been designed for children with the idea of developing investigative behaviour and discovery. In the Inventorium for 3- to 6-year-olds, visits take place in two stages. The children first explore familiar themes such as water, the weather, bread and the home. They can then go on to activity areas.

The Inventorium for 6- to 12-year-olds is a more spacious and more sophisticated area, in which the children have access to do-it-yourself-type exhibits, such as a miniature television studio, or animal life, such as an ant colony whose members are fed at regular intervals.

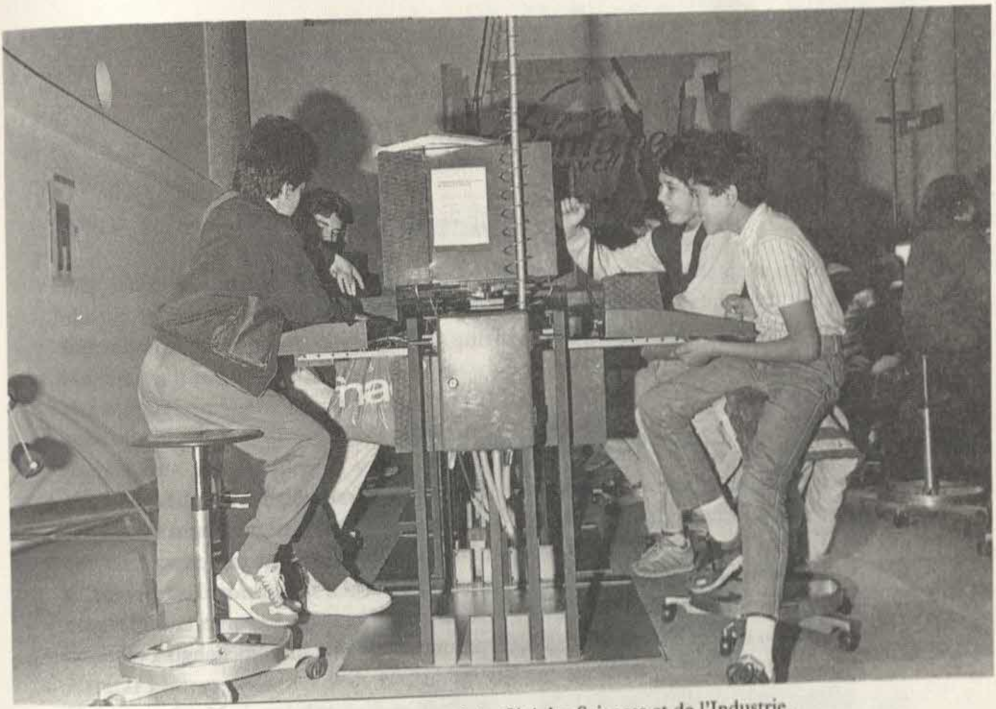
The youngsters are not confined to these two reserves, however. They are to be found all over the Cité and make up 70 per cent of the visitors. They come for an afternoon with their teacher or for a fortnight under what is known as the Villette Classes scheme. Each class draws up a project, the teachers having received a four-day briefing at the site beforehand. The teachers work in collaboration with the Cité's own demonstrators. In 1986 the Cité hosted ninety Villette Classes; it will soon be able to accommodate from eight to ten classes on the premises at the same time. This will be a fantastic adventure for those children who live outside the capital.

### *The House of the Regions*

This facility enables the Cité to collaborate with different regions of France to produce exhibitions of regional origin. For instance, an exhibition was mounted on the history of culinary practices based on research on nutrition in the past. Meals and dishes served at the time of Louis XIV were reconstituted and served by costumed waiters to the accompaniment of music of the period.

### *The Louis Lumière Film Club*

Here scientific and technological knowledge is disseminated by films on a permanent basis. The film club is an aid to teachers, bringing them into contact with researchers and film-makers, and helps to interest young people in science.



Learning is fun at the Médiathèque of the Cité des Sciences et de l'Industrie.

Wandering through the Cité des Sciences et de l'Industrie's Robot Zoo (Explora, Section III), it is hard to resist Gilles Roussi's robot.

*Photos*: Bernard Baudin/Cité des Sciences et de l'Industrie

### The Conference Centre

With an adaptable room seating 1,000 people and a number of smaller rooms and temporary exhibition areas, the Conference Centre can host meetings of outside bodies related to the Cité's aims ranging from scientific congresses to industrial events.

### The science newsrooms

Designed and run jointly with the Association des Journalistes Scientifiques de la Presse d'Information, these rooms present science news by means of small displays, journalists' reports and on-the-spot discussions recorded and reproduced on the Cité's screens. (An example is the eruption of carbon dioxide in Lake Nyos in Cameroon.) They help the Cité to keep abreast of current research and of major debates on topical issues such as the environment, quality of life, changing patterns of work and bioethics.

### The Multimedia Library

Extending over a very large area (12,000 m$^2$), the Multimedia Library occupies three storeys on the south-facing side of the conservatory, from which the Géode can be seen. It can cater for 2,000 users a day. Its 100,000 volumes (there will soon be 300,000) and 5,000 periodicals cover every sector of scientific, technical and industrial activity. It also has science fiction and comic-strip books and there is an area of 700 m$^2$ with special publications for children.

Researchers into the history of science and technology and the dissemination of knowledge (didactics and museology) also have their own library, whose holdings will eventually total 80,000 volumes.

The whole of the catalogue is accessible to the public on the site through viewing consoles, and even in private homes through the Minitel system.

The most novel aspect is the area for the consultation of visual material (films, photographs and video) recorded on videodiscs. Discs are presented simultaneously through 180 consoles. An automatic distributor (visible behind glass) picks them out from some 500 piles and places them in position for reading.

Finally, general information on the Cité, science news and games are accessible in the home through the SEVIL host centre to any telephone subscriber having a Minitel terminal.

# The dissemination of scientific and technical information in France

CSI involved an investment of 4,000 million francs ($600 million) to rehabilitate a building as a functional complex extending over an area of about 1 million m$^2$; it also requires an annual expenditure of about 700 million francs ($116 million), far less than 30 per cent of which is covered as yet by receipts, although it is visited by from 3 to 4 million people every year. Such a development might well have exhausted all the energies and funds available for this kind of activity. This was very much feared when the project was launched in 1979. Strange to say, the effect has been quite the opposite.

This remarkable project drew and will draw many others in its wake. At present interest has focused on the revitalizing of existing institutions, which would be less costly to develop than the CSI—as, for instance, the Palais de la Découverte, the Natural History Museum and, to a lesser degree, the Musée de l'Homme or the Conservatoire National des Arts et Métiers. A new dynamic spirit prevails at the head of these institutions. Funds, still limited but enough to provide a strong incentive, have been made available by the state and also by some patrons.

There is also a noticeably strong desire on the part of regional cities to have some cultural centre for exhibiting their scientific, technical and industrial achievements and particularly their will to modernize. The 'Futuroscope' near Poitiers, the Halle Tony Garnier in Lyons and the projects in many cases well under way at Grenoble, Strasbourg, Marseilles, Nice, Toulouse, Bordeaux and Montpellier have been conceived by local authorities and communities. They combine a concern for progress with a high standard of science and technology as a guarantee of developement; their games and media-like aspects attract the public; and sound management of expenditure and resources minimize the burden of such facilities in terms of capital expenditure and running costs.

Similarly, the experience gained by French firms in the development of the CSI can serve in other operations of the same type, even if financially they are on a smaller scale.

The major research bodies—the Centre National de la Recherche Scientifique (CNRS), the Institut National de la Santé et de la Recherche Médical (INSERM), the Institut National de la Recherche Agronomique (INRA, agricultural research), etc.—have realized what is at stake in the dissemination of scientific knowledge to different publics. The need to understand what basic research represents and its use as a social factor for healthy enterprise by virtue of the transfer of knowledge and expertise, and the importance of maintaining the conditions necessary for sustaining national research at the highest international level encourage these research institutions to facilitate the dissemination of scientific and technical information even among the lay public. The example of the CNRS is the most significant in this respect, with its staff of 26,000 and an annual budget of 9,000 million francs.

On the one hand, it has set itself the task of systematically encouraging *direct relations between researchers and young people*, particularly in schools, under the operation known as 'A Thousand Classes—A Thousand Researchers' launched in 1985. This led to the twinning of several hundred laboratories and volunteer researchers with classes in secondary schools. In each case a project is developed jointly, sometimes leading to a small exhibition, always facilitating contacts between the students and the real world of ongoing research.

On the other hand, the CNRS has developed or set up small technical teams responsible for maintaining liaison with the world of the media and communication. This has led to the production of series of television programmes for young people (two series of thirty-nine programmes entitled *Le monde selon Georges*). They were based on films made in the laboratories or by researchers, which were edited to make them suitable for a young audience.

This energy-measuring device is one of the many hands-on exhibits at the Cité des Sciences et de l'Industrie (Explora, Section III).
*Photo*: Bernard Baudin/Cité des Sciences et de l'Industrie

It also led to the establishment of the Bellevue Exploration Workshop, in which scientists in collaboration with communication specialists prepare interactive 'models' informing the public in a readily understandable way of their findings, theories and research tools. These 'models' can be used on occasions when laboratories are opened to the public for visiting, or when they organize special exhibitions such as the large CNRS national exhibition in 1984 on the theme of communication, or again in science and technology centres such as CSI.

This science communication know-how was already present to some extent in popular science publishing and has developed considerably in recent years with the publishing of books (the 'Odile Jacob' series and the publishing house of the same name; all the major publishers now have a popular science series) and in the publishing of periodicals and the advent of a new generation of science journalists.

Science communication was not much in evidence on French television until recent changes brought about a positive trend in the production of programmes on science. However, it is still way behind British or American television in this respect. Science communication through exhibitions was practically non-existent, though it has developed considerably over the past five years, as we have seen.

## Conclusion

The past decade has undoubtedly witnessed an unprecedented effort in France on behalf of wider dissemination of science and technology among the general public. This knowledge has been disseminated on a new basis, science and technology being assimilated into their industrial and economic environment with man placed at the centre, thus encouraging a thematic rather than a disciplinary approach. All the new mass media have been brought into play. A novel type of relationship between science, communication and society has come into being and is not unconnected with a deep-seated change in the mental habits of the French.

A less restricted viewpoint, one more concerned with the functioning of a society evolving towards modernity, is emerging. Accepting more readily the need for enterprise, transcending the traditional rift between classical education and scientific training through the communication of the adventure of science and technology, rejecting both a naïvely triumphant attitude towards progress and the absolute pessimism of a science and technology born of war, present-day French society is visibly changing and it is scarcely possible as yet to predict the outcome.

# Part V

# Materials and methods for science and technology education

# Introduction

Practical work in school science and technology education is currently undergoing a long overdue reappraisal. As has been argued by a number of commentators, much that students do in school laboratories can be aimless, trivial and badly planned. For certain purposes, a teacher's demonstration or a computer simulation may be more appropriate than individual practical work by each student. The situation now is that the range of available means had increased significantly with developments such as those in software, computer-based learning packages, electronic sensors and integrated measurement systems. A clearer indentification of the learning outcomes intended—a familiarity with materials and natural events, enhanced motivation to learn, the acquisition of laboratory skills, understanding of the processes by which scientific knowledge has been acquired, or understanding of an important scientific idea—needs to be accompanied by a critical review of available means so as to achieve a better match.

The first two chapters that follow relate directly to this issue. Adnan Badran offers suggestions for the redesign of practical activities to make them more supportive of the aims of courses dealing with the interactions of science, technology and society, while Ramiro Tobón argues that low-cost materials can be superior to sophisticated equipment in helping children to grasp scientific principles. Whereas there is much to be said for simplified apparatus adapted from cheap or discarded items, he sees the availability of the products of 'advanced technology', for example inexpensive integrated circuits or pressure transducers, as obliging a reconsideration of the distribution of effort. The particular circumstances of a country, and of a school within it, will be a major determinant of what Tobón calls the 'blend of low-, medium- and high-cost equipment' to be used. He also offers thought-provoking comment on the non-educational contextual factors that influence decisions about the choice of equipment to be imported when a country is obliged to rely for some of its science and technology teaching resources on foreign suppliers.

Equipment is not to be thought of as a passive tool of curriculum planners, however, cast in a solely instrumental role for the achievement of predetermined ends. That the relationship between educational ends and means is an interactive one is well illustrated by George Marx's chapter on the place of the computer in the teaching of science and technology. Here the instrumentality creates new educational options. Possibilities are opened up for all kinds of learning which previously were unavailable. Thus, it is his assertion that the 'full predictive power of the Newtonian dynamics has become teachable . . . only by the advent of microcomputers'. Just as in the nineteenth century cheap steel pen nibs moved writing into the realms of a universally acquirable skill, because for the first time in history everyone could practise the skill and achieve mastery, so, Marx argues, the scientific imagination and understanding of students can now be educated by the computer in ways which hitherto have been difficult, if not impossible, to achieve.

The assessment of students' practical work is one of the themes of the chapter by Geoff Giddings and Barry Fraser, though their interpretation of practical work is the traditional one of experimentation in the science laboratory. Even so, they reveal some of the formidable difficulties involved, not least with more recent attempts to make continuous longitudinal observational assessments of students' laboratory activities. A danger here is that techniques of assessment, constrained by pragmatic considerations such as limited time and large classes, will have an adverse wash-back effect on the nature of the practical activities in which students engage in science laboratories. Reference was made in the Introduction to this volume to a comparable set of problems afflicting the assessment of project work in technology education.

The theme of assessment is developed further by Giddings and Fraser in their account of techniques for the assessment of children's attitudes to science and for the assessment of the classroom environment in which learning takes place. In a complementary discussion of large-scale studies at national and international level, Malcolm Rosier provides a concise review of approaches adopted in order to make comparison of the attainment of students studying science. He draws for this on the experience of the Second International Science Study, started in 1981 under the auspices of the International Association for the Evaluation of Educational Achievement (IEA), so that solutions to the problems of divising 'a fair test' for students who are working in very different educational contexts and receiving very different curriculum experiences are illustrated by specific examples.

It is appropriate that the final chapter of Part V, and indeed of the volume, should be devoted to the education of teachers. All that we have learnt about innovation in science and technology education since the major curricular interventions of the 1960s has confirmed that teachers are the key resource for the achievement of change. Curriculum materials, aids of various kinds and support systems are, of course, important. But unless teachers understand the innovation and believe in its intentions and pedagogical means, the best resourced endeavours will be vitiated in the classrooms and laboratories. Colin Power takes his readers systematically through the various stages in the formation of a professionally qualified and committed teacher—recruitment, selection, pre-service programme, induction and continuing in-service education—demonstrating their integrity and raising many important issues. His conclusion that effective teaching involves selecting and orchestrating from a larger repertoire those strategies, methods and materials judged appropriate to the particular context and to the teacher's goals, rather than mastering and applying a few generic teaching skills, is particularly significant for the experiences we offer to students on teacher-training programmes. Similarly, the changing patterns of in-service training, including school-focused activity, which he describes, have direct relevance to the implementation of innovations. The quality of a nation's teaching profession is the prime determinant of the possibility for change. As he concludes, 'there is no path to excellence other than the extension and refinement of the professional judgements, knowledge base and social sensitivity' of teachers.

systematically through the various stages in the formulation of a professionally validated and confirmed [illegible], pre-service programme, induction and continuing in-service education, sustaining their integrity and vitality at important levels. His conclusion that effective teaching involves selecting and orchestrating from a large repertoire those strategies, methods and materials judged appropriate to the particular context and to the teacher's goals, rather than mastering and applying a few generic teaching skills, is particularly significant for the experience we have of teacher-training programmes. Similarly, the changing patterns of in-service teaching, including school-focused activities which he describes, have direct relevance to the implementation of innovations. The quality of a teacher's teaching profession is the prime determinant of the possibility for change. As he concludes, 'there is no path to excellence other than the enrichment and advancement of the professional judgement, knowledge-base and moral commitment of teachers.'

# Practical work in the teaching of science and technology

Adnan M. Badran

## Meaning and scope

Practical work plays a central role in science education. It provides learners with opportunities to use scientific equipment, to develop the basic manipulative skills and attitudes needed for future work in science and to practise investigative and inquiry activities. It also enables children to be actively involved in learning.

Science education has become increasingly concerned with the interaction between science, technology and society. Thus there is a need to design practical activities for children which reflect this wider scope of science education. We cannot rely on models from the past because, according to Lauda (1984), 'the growth of science and technology has given today's children a totally new perspective that requires a different approach to understanding their technical means. It involves responding to change and helping children understand its impact on their lives.'

This orientation of science education towards integrating science, technology and society has led science educators to call for the teaching of meaningful practical skills. This entails the teaching of some applications of science and technology as well as an understanding of scientific knowledge and processes (Fensham, 1981). Social relevance and applicability to problem situations in the real world are, therefore, considerations in the design of practical activities which now need to be taken into account in addition to well as understanding scientific knowledge and methods of working. The following examples of practical activities reflect these criteria.

### *Activity 1. How a geyser is formed*

(Science Education Center, 1981*a*)

*Materials*

Erlenmeyer flask
Rubber stopper
Rubber stopper, one-holed
Glass tubing
Tripod
Alcohol burner
Test tube holder
Cloth

### *Procedure*

Half-fill the Erlenmeyer flask with water. Fit the glass tube into the one-holed rubber stopper. Fit this rubber stopper into the flask opening (Fig. 1A). Heat the water. Observe what happens to the water.

What happens to the water in the flask as it is heated?

Is the volume more or less?

Slowly remove the one-holed rubber stopper from the flask. Heat the water until it boils. Allow the water to boil for at least five minutes (Fig. 1B). Tightly close the flask with the rubber stopper without a hole. Slowly turn the covered flask upside down (Fig. 1C). Make sure the hot water in the flask does not leak out. Let the water in the flask cool for a few minutes. Look at the surface of the water in the flask. You may place a wet cloth on the flask (Fig. 1D). Describe what you see.

### *Commentary*

Under normal air pressure, water boils at 100 °C. In this activity, water boiled at a temperature below 100 °C because of lowered air pressure (Fig. 2). Before heating, air pressure in and out of the flask is equal. As the water in the flask becomes hot,

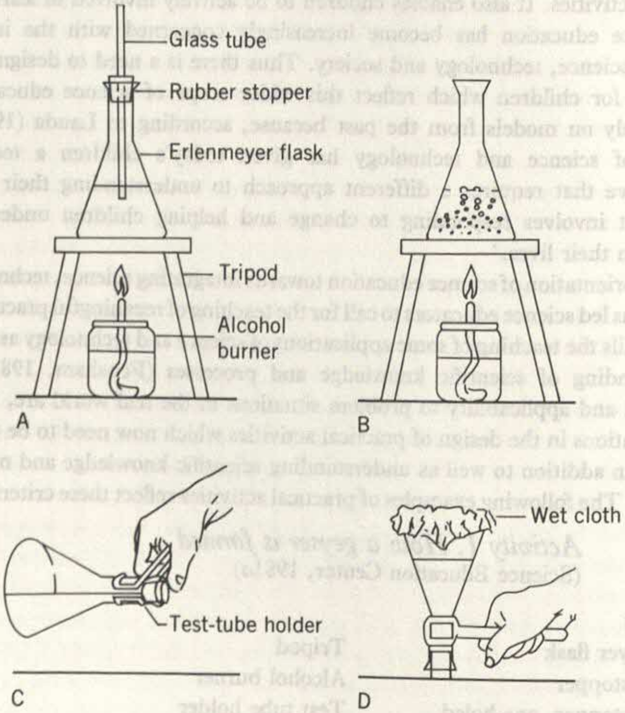
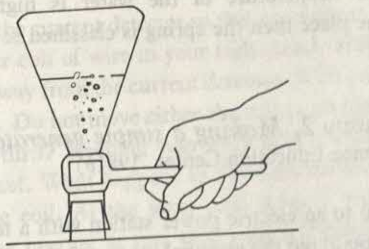


FIG. 1.

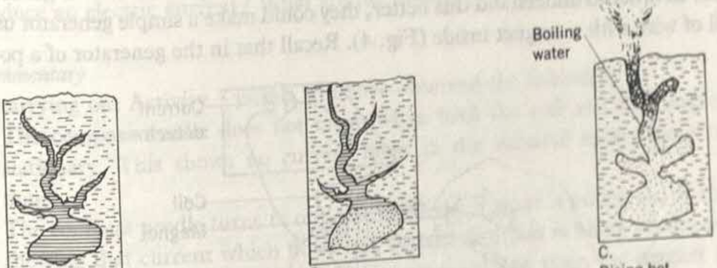
air in it is also heated. Hot air rises out of the flask. Less air in the flask results in a lower pressure inside than outside the flask. Putting the stopper in the flask prevents the air outside from getting in. Since the water is hot, some water evaporates. The pressure of the water vapour in air raises the pressure in the flask. As the hot water in the flask slightly cools, the air in it also cools. Some water vapour changes back to water. The low air pressure causes some gases in the hot water to rise to the surface as bubbles. This shows that under low air pressure, water boils at a temperature lower than 100 °C.

All geysers are formed in the same way. When water in the soil several kilometres underground comes near hot rocks it becomes hot (Fig. 3A). Water at this depth has a temperature sometimes above 100 °C but it does not boil. This is due to the high pressure at this depth. As the water near the hot rock is heated, it



Lowered air pressure
in the flask causes water
to boil at a temperature
below 100 °C

FIG. 2.



A.
Water
in the soil
absorbs
heat from
hot rocks

B.
Heated water
at great depths
does not boil
due to great
pressure.
It pushes
up the water
above it

C.
Rising hot
water begins
to boil at D
where pressure
is lower due
to cracks
in the rocks

FIG. 3. Formation of a geyser.

expands and pushes up the water above it (Fig. 3B). Water rises through cracks in the rocks. Since air pressure near the surface is lower, there the hot water begins to boil (Fig. 3C). Some of this water changes to water vapour, or steam. The pressure increases. When the pressure becomes strong enough, the water is pushed out with a force that shoots it up into the air.

After an eruption, pressure decreases. Water seeping in is again heated. The cycle is repeated. A geyser appears so long as there is water. When the supply of water is cut, or when it is channelled to some other place, the geyser may disappear.

Where there are no cracks or openings to the surface, the hot water mixes with the groundwater which slowly moves along the porous rock layer. It eventually finds its way to the surface through cracks along the mountainsides. A spring forms. When the temperature of the water is higher than the average air temperature of the place then the spring is classified as a hot spring.

## *Activity 2. Making a simple generator*

(Science Education Center. 1981*b*)

The class could go to an electric power station with a teacher. A resource person could be asked to point out the essential parts of the generator and to explain how it produces electric current.

Hospitals, cinemas, large department stores and universities usually have small generators. A class could visit these places if there is no electric power station close to the school.

After the visit, pupils will most probably have a rough idea how a generator works. In order to understand this better, they could make a simple generator using a coil of wire with a magnet inside (Fig. 4). Recall that in the generator of a power

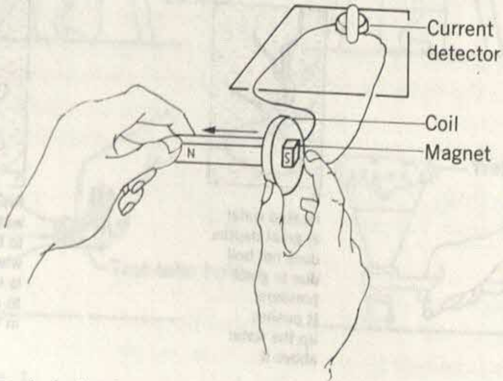


FIG. 4. A simple generator.

station an electromagnet is used instead of a simple permanent magnet. The reason why this is so will become clear in the next activity.

### *Activity 3. How a generator produces electric current*

(Science Education Center, 1981*b*)

*Procedure*

Make a coil of about fifty turns of insulated copper wire and connect a current detector to it.

A current detector is made by winding about twenty-five turns of insulated copper wire around a simple compass. When a current flows through a coil of wire, a magnetic field is set up around it. This magnetic field causes a compass needle to move.

Adjust the compass of the current detector so that its needle is parallel to the coil around it. Hold the bigger coil of wire in your right hand. Make sure the coil of wire is at least one metre away from the current detector. With your left hand, place the magnet inside the coil. Do not move either the coil or the magnet. Look at the compass needle. Does it turn? Keeping your eyes fixed on the compass needle, quickly pull out the magnet. What happens to the compass needle? Now put the bar magnet back into the coil. At the same time observe what happens to the compass needle. Keep the magnet at rest with your left hand. With your right hand, move the coil of wire quickly towards and away from the magnet. What happens to the compass needle? Repeat, but this time move the coil as fast as you can. What do you notice about the movement of the compass needle?

Making use of your observations when you moved either the magnet or the coil, describe how current is produced in the coil. What is necessary for the generator to produce an electric current? What are the essential parts of a generator?

*Commentary*

In carrying out Activity 3 pupils will have observed the following:

1. The compass needle does not move when both the coil and the magnet are stationary. This shows no current flows in the detector under these conditions.
2. The compass needle turns to one side when the magnet is pulled out of the coil showing that current which flows in a certain direction is being produced.
3. The compass needle is deflected to the opposite side when the magnet is put back into the coil. This again shows current is produced but this time it is flowing in the opposite direction.
4. Similarly, when the coil of wire is moved towards and then away from the magnet, current that flows alternately in opposite directions is produced.

When the magnet is moved in and out of the coil or when the coil is moved towards or away from the magnet, the magnetic field of the magnet is cut by the coil of wire.

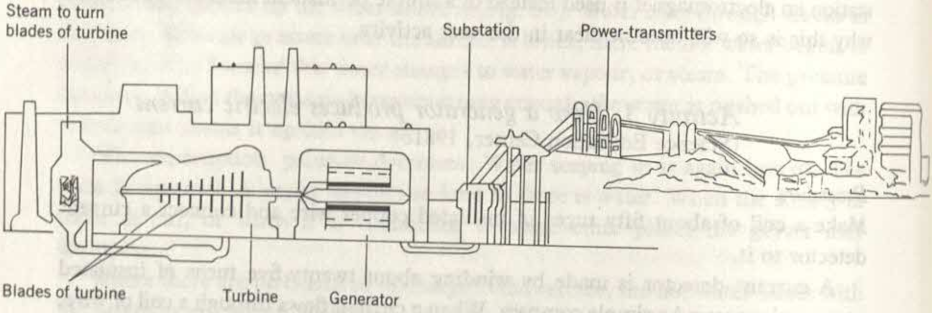


FIG. 5. Diagram showing the production and transmission of electricity.

It is only when this happens that electric current is produced. Current produced without direct contact is called an induced current and the process is called electromagnetic induction.

It is the movement of the magnet in and out of the coil or of the coil towards and away from the magnet that produces the electric current in the closed circuit. So it is through the process of electromagnetic induction that a simple generator produces an electric current.

We can now go back to see how the generator at the power station works. Recall that the generator in the power station has a coil of wire and an electromagnet. The coil of wire in the generator at the power station is actually similar to the coil in the simple generator except that it is very much bigger. However, instead of the bar magnet, as in the simple generator, an electromagnet is used. An electromagnet is also a coil of wire around an iron core.

An electromagnet is used because it is lighter and hence easier to move than a heavy, permanent magnet. Also, it has a much stronger magnetic field than a permanent magnet.

The other difference is that instead of moving the electromagnet by hand, as in the case of the simple generator, the generator at the power station has a big wheel called a turbine connected to the iron core of the electromagnet (Fig. 5). When the turbine turns, the electromagnet moves with it. When there is a large current in the coil of the electromagnet, there is a strong magnetic field around it. When this electromagnetic field is cut by the big coil of wire surrounding it, a large induced current is produced in the coil of the generator.

## *Activity 4. How a turbine turns*

(Science Education Center, 1981*b*)

*Materials*

Cigarette foil, 10 × 4 cm
Dressmaker's pin
Empty milk can
Scissors
Paste
Paper, 2 × 2 cm
Burner (alcohol, paraffin, electricity or any heat source like firewood)
Tripod or stove out of empty milk can
Nail
Pencil with eraser
Match

*Procedure*

1. Use the nail to make a hole in one end of the empty milk can as in Figure 6. Make the hole about 1 cm in diameter.
2. Cut the cigarette foil into two equal parts such that each part measures 10 × 2 cm. Paste the parts together to form a cross (Fig. 7)
3. Cut the edges along the broken lines (Fig. 7)
4. Fold the piece of paper twice to form a small square that fits the centre of the

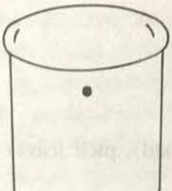


FIG. 6.

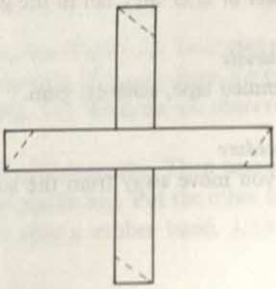


FIG. 7.

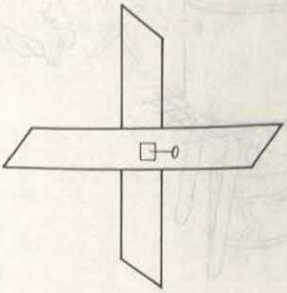


FIG. 8.

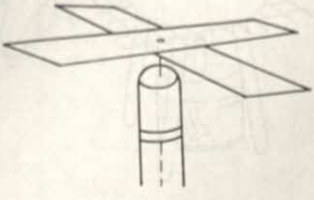


FIG. 9.

cross. Use this square to help hold the cross in place by inserting a pin through it (Fig. 8).

5. Stick the pin to the eraser of your pencil or tape it on a small stick (Fig. 9).
6. Pour water into the empty milk can until it is half-filled. Cover the two holes on top of the milk can with paper (Fig. 10).
7. Boil the water in the milk can as in Fig. 10. If a tripod is not available, make a stove using three stones. Then use paper and small pieces of wood instead of the burner to light a fire in the stove.
8. Wait until steam comes out of the single hole at one side of the can. Use the pencil stick to hold up the paper cross. Let the steam hit the arms of the cross (Fig. 11).

### *Activity 5. Environment protection day-demonstration of dust pollution on plants*

(National Authority for Environment Protection and Nature Conservation, 1984)

Fine particles of soil are carried into the air both naturally (by wind, animals, etc.) and artificially (by cars, factories, etc.). Depending on the mass of the particles, sooner or later they fall to the ground and on to plants.

*Materials*

Gummed tape, scissors, gum.

*Procedure*

As you move away from the source of pollution (e.g. a road), pick leaves from

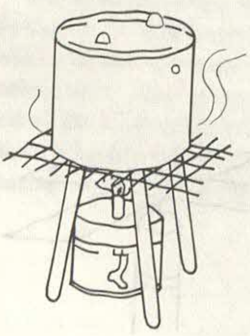


FIG. 10.

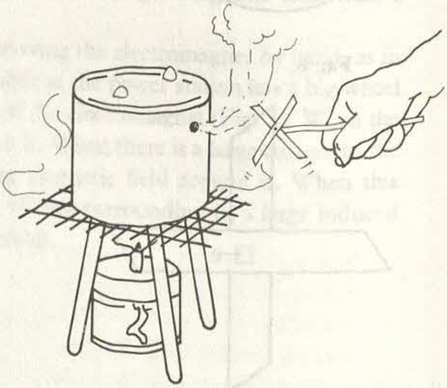


FIG. 11.

plants at the same height each time. Make a print of the leaves with gummed tape. If you are skilful and careful you can do it without tearing the leaves. Note carefully the distance of each leaf you pick from the source of pollution. Stick the prints of leaves made in this way into your notebook. How does the degree of pollution on leaves change as you move away from the source of pollution?

### *Activity 6. What gases are present in polluted air?*

(RECSAM, 1979)

There are many kinds of gases and substances in polluted air which are harmful and poisonous to man and animals. One kind of gas that is produced much more than other kinds is carbon dioxide. Its presence can be demonstrated by performing the experiment below.

*Materials*

3 plastic bags
2 glass tubes 300 mm long and 10 mm diameter.
2 test tubes containing 5 ml of calcium hydroxide solution.
Spiral wire

*Procedure*

Collect gas from the exhaust pipe of a motor cycle, as in Figure 12. Take care not to breathe in any of the exhaust gases. Gently bubble some of the gas from the plastic bag through the solution of calcium hydroxide (Fig. 14). What do you observe and what conclusion do you draw?

Collect smoke by taping a cigarette to the end of a glass tube. Then tape a wire around the tube to stop the cigarette burning the plastic bag. Put the other end of the glass tube into a flat plastic bag and tie it with a rubber band. Light the

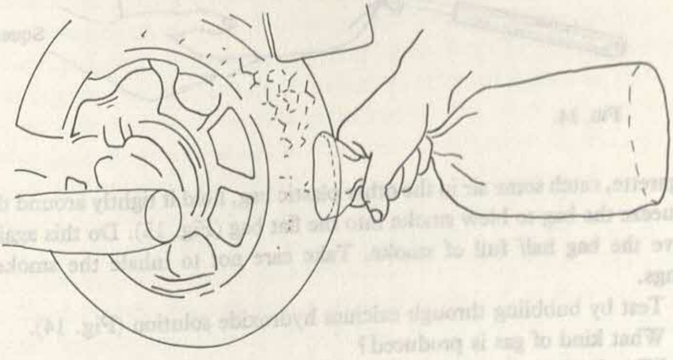


FIG. 12.

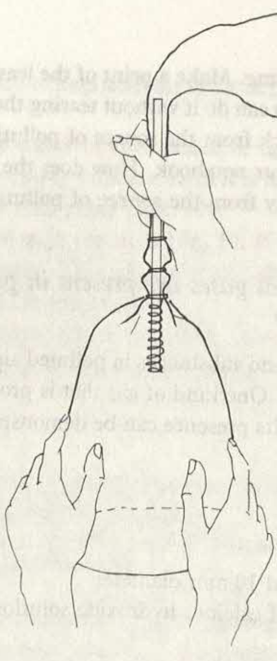


FIG. 13.

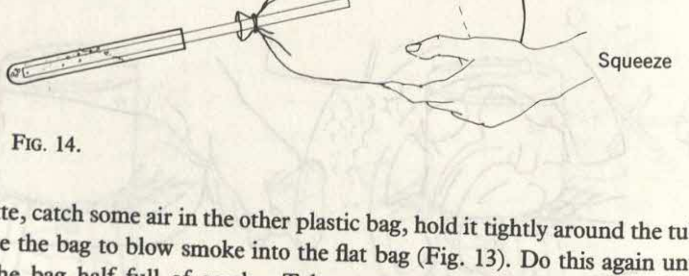


FIG. 14.

cigarette, catch some air in the other plastic bag, hold it tightly around the tube and squeeze the bag to blow smoke into the flat bag (Fig. 13). Do this again until you have the bag half full of smoke. Take care not to inhale the smoke into your lungs.

Test by bubbling through calcium hydroxide solution (Fig. 14).
What kind of gas is produced?
Why do you say so?

## References

FENSHAM, P.J. 1981. Head, Hearts and Hands. *Australian Science Teachers Journal*, Vol. 27, No. 1, pp. 53–60.

LAUDA, D. 1984. Technology Education and Closing the Gap between Theory and Practice. *The Technology Teacher*, Vol. 43, No. 6, pp. 4–6.

NATIONAL AUTHORITY FOR ENVIRONMENT PROTECTION AND NATURE CONSERVATION. 1984. *Environmental Education: Fieldwork*. Budapest.

RECSAM (REGIONAL CENTRE FOR EDUCATION IN SCIENCE AND MATHEMATICS). 1979. *Science through Activity*. Penang, Malaysia, RECSAM.

SCIENCE EDUCATION CENTER. 1981*a*. *Geothermal Energy*. Quezon City, University of the Philippines, Diliman,

——. 1981*b*. *Electricity from Underground*. Quezon City, University of the Philippines, Diliman.

# Low-cost materials for science and technology education

Ramiro Tobón

## Introduction

To many people in education systems throughout the world, low-cost materials and equipment mean second-rate science and technology education for their children. They regard low-cost materials as something of a necessary evil, a consequence of insufficient wealth in their societies to afford first-rate equipment which makes use of the latest available technology.

While there is some truth in the economic part of these beliefs, there are also substantial misconceptions. I shall attempt to analyse the issue, presenting its positive and negative aspects, in the hope of helping teachers and administrators to make their decisions after giving careful thought to different aspects of the problem.

## Why low-cost materials?

Usually low-cost materials are produced in the country where they will be used. From the economic point of view, therefore, they save scarce foreign currency. In these times of high foreign debts run up by developing countries, this point is quite important and applies to the purchase of equipment of low, medium and high cost. Having enough imported equipment in each school to allow children to experiment by themselves in small groups would be very expensive, even if foreign currency were not especially scarce in the country.

But economic considerations alone should not determine the course of action for an education system. Low-cost equipment and materials may have pedagogical advantages. I use the word 'may' to qualify this statement, because the pedagogical advantages depend largely on how the materials are designed, produced and used within the education system. Low-cost materials usually are simple in design to allow students to understand more easily the underlying principles. Many sophisticated pieces of equipment come as completely enclosed units whose inner workings are usually not understood by the user.

Teachers and administrators are frequently concerned about the damage students can cause to expensive imported equipment for which there is neither a local and/or national supply of spare parts nor a work-force of qualified technicians to do needed repairs. Numerous examples could be given of major investments in equipment and materials that are not used to teach science and technology to pupils, but instead are carefully locked away to be shown to distinguished visitors to the school. With great care and apprehension the teacher may use some of this precious equipment for demonstrations, but students are not allowed to touch or manipulate it. Thus the expenditure of scarce foreign currency and the long negotiations to secure donations or loans from foreign governments or international organizations are almost a complete waste.

Low-cost material and equipment make teachers and administrators less concerned about possible damage when students make direct use of them. The provision of spare parts for, and the repair of, locally produced equipment are not difficult problems if the equipment is built at the school using locally available or scrap materials.

However, we have to ask ourselves whether the use of low-cost materials leads to a lower quality science and technology education? Let us first answer this question with some other questions. What is the quality of the education given when expensive equipment is kept locked away and never used by students? Do we obtain good quality education when teachers make a few demonstrations using expensive or sophisticated equipment?

Low-cost, simply designed equipment is not synonymous with second-rate science and technology education. The challenge to be met in designing and building equipment for science and technology education is to produce experiments that are relevant to the student and that lead to understanding. Many sophisticated and expensive pieces of equipment are used to perform experiments that do not assist the learning of the syllabus of a particular science subject. The student may be impressed by the beautiful equipment, but is not helped to understand the underlying principles.

Finally, it needs to be said that the use of low-cost simple equipment is not a concern of developing countries only. Many industrialized nations have introduced low-cost equipment for pedagogical reasons, recognizing that its use can enhance students' understanding.

## Curriculum and materials

Ideally the development of textbooks, equipment and other materials should be an integral part of the development of new curricula. On this subject, C. Crellin has stated (Unesco, 1983, p. 15):

> There is no doubt governments give very much more priority to the teaching of science through the indirect media of the printed word than through learning from experience. Thus few countries lack curriculum development programmes where textbook production is the ultimate goal. Fewer countries have effective equipment development and production teams, and many of these work in isolation from textbook development teams.

I would add that even to import equipment a close co-ordination between curriculum and equipment is of paramount importance. But when equipment is bought abroad, the main concern usually is to see which country or company offers the best credit terms.

The change from a teacher-centred to a student-centred education is also hindered by the over-theoretical training of many teachers. They lack the familiarity and the self-confidence to undertake experimental and practical instruction whereby children are allowed to play with equipment and materials and to display their own initiative. Not enough attention is given to the practical training of teachers, both in their pre-service education and in their in-service training. Although teachers receive textbooks and written curriculum guidelines about 'active' education of their pupils, they are frequently left to fare for themselves in the matter of procuring materials and equipment to implement this 'active' education. The development of low-cost materials and the adequate training of the teachers can contribute significantly to the overcoming of such problems.

## Strategies for implementation

There are many ways to implement national or local production of low-cost materials. The choice depends on national and local conditions. Some strategies that could be considered are as follows:

1. The distribution of detailed designs which enable teachers and/or students to build the equipment and materials.
2. The supply of designs and some 'critical parts' that teachers are not able to find easily in their local communities.
3. The supply of parts and some ready-to-make sets and instruments with detailed instructions. Teachers and students would assemble the equipment together.
4. The supply of complete sets or kits for the experiments in each grade of the curriculum.

5. The supply of assembled equipment or kits with all needed items for the assemblage of the equipment and written materials for adults in distance education.
6. The application of some combination of the strategies listed above.

The first of this list of strategies is sometimes associated with 'improvised' equipment, a rather unfortunate term. In fact, the designs have to be carefully chosen and tested, and need to be appropriate to the aims and objectives of the curriculum. The equipment has to be built with materials and parts easily found in the local communities. Thus a lot of careful previous planning has to be done before teachers and students get to the stage of 'improvising' the equipment.

The second strategy seeks to avoid the failures and frustrations associated with the first, when important experiments have often to be omitted due to the lack of small items that cannot be found in the local market. For instance, the design may call for a small lens taken from a penlight bulb, but such bulbs might be difficult to find locally.

The third strategy takes into account that not all items of equipment which are needed can be built by teachers and students. Measuring devices and instruments such as voltmeters, ammeters, etc., need to be supplied.

The fourth strategy is exemplified by those cases in which the Ministry of Education or private enterprise sets up a special centre and/or industry to produce equipment for the whole education system. While these centres operate on a relatively large scale with the possibility of reducing unit costs, they often do not keep in close contact with teachers and with curriculum developers.

The fifth strategy could be used for adult education, where the kits could be distributed through community groups such as town councils or similar bodies which are able to take responsibility for the local support.

These and other strategies can be blended to fit national and local needs. Local artisans, technicians and craftsmen could work together with teachers and school administrators to build equipment appropriate to curricular needs and which might also be used to up-grade the science and technology background of parents and other adults in the community.

If an integrated curriculum exists, that is, one that integrates science and technology education, the first three strategies should be given special consideration. If the technological component includes the development of a number of practical skills by the children and young people, then the production of pieces of equipment to develop some experiments for the science component of the curriculum can help in the integration of the two components.

When teachers and students are involved in the production of simple but adequate equipment, they know how to do repairs and are no longer afraid of taking the equipment apart. With imported equipment, teachers are very much afraid of dismantling the equipment to find out what is wrong with it. In many places teachers are financially liable for any damage to the equipment and the liability persists even when the equipment is so old that its normal useful life is over.

## Appropriate versus advanced technology

The local production of low-cost equipment is often cited as an example of the development and use of 'appropriate' technology. Its main objective is to have equipment, adapted to the curriculum, that can be built from discarded items, such as metal and plastic containers, paperclips, pieces of cardboard, etc., and which is complemented by relatively few items (or critical parts) provided nationally by the country's industries or by means of imports.

But the 'low-cost' qualification need not exclude the use and appropriation of modern technology. This can be best illustrated with an example. For the teaching of science to young people in their final years of secondary education, instruments such as voltmeters and ammeters are needed. Building traditional moving-coil analogue instruments needs a high level of craftsmanship and, if attempted, will probably yield only a small percentage of items of suitable quality.

Electronic meters, on the other hand, can be built without the craftsmanship of a watchmaker. In an integrated science-technology curriculum, transistors, diodes, operational amplifiers and simple integrated circuits should be included, to prepare students to live in a world that already depends to a great extent on these devices. Then building digital meters becomes an interesting and worthwhile exercise that will provide the school and the students with instruments to carry out many experiments in physics, chemistry and biology, with adequate precision.

Building sensitive balances or scales using appropriate pressure transducers is another example. Such balances can then be used in many applications throughout the school from the elementary to the secondary level. Even in universities these would be worthwhile projects for young people who did not have the opportunity to familiarize themselves with these technological advances in their previous schooling.

The integrated circuits would have to be imported, but when bought in medium or large quantities they are very cheap. A national centre or an industry could produce printed circuits to make the building of instruments a task easily realizable at the school level. Some 'critical parts', to use the term once more, would have to be provided.

Clearly a great deal of attention has to be given to the in-service training of teachers who are not familiar with modern electronic devices. After a basic training in electronics, the teachers would have to build and test, as part of their in-service training, one or two prototypes of each instrument to be built in the schools later on.

## Low- and high-cost equipment compared

Imported expensive equipment does not necessarily guarantee high precision in the measurements made with it or in the applications described by the manufacturer. It is quite common to see beautifully made boxes with two chrome terminals that contain just a carbon resistor or a capacitor of commercial quality (usually ± 10 per cent of the rated value). A box like this may have cost $25 whereas all that is needed is a resistor or a capacitor costing a few cents and two terminals. The box can be built with hand tools by people with little training and the precision would be the same or better, because one could buy resistors or capacitors with tolerances of ± 5 per cent or even ± 2 per cent without increasing the cost significantly. It is almost a crime to expend a great many dollars of hard-earned foreign currency to buy resistors and capacitors accurate to only ± 10 per cent. Mechanical devices (such as pulleys) always have friction and it is very difficult to design and build equipment of this type that gives experimental errors of less than 3 or even 10 per cent. Pulleys, spring guns and other similar devices can be easily built by technicians using machines such as lathes, drills and milling machines. These technicians and their machines are usually already there in the education system in technical secondary schools and technical colleges. The young people being trained in those schools could easily build many components in the course of their training. In many communities, artisans and mechanics with the necessary skills are also at hand and could be called upon to make some of the critical parts difficult to manufacture without the appropriate tools and training.

Almost any measurement requiring a precision of 1 per cent or less calls for sophisticated apparatus and great care in the choice of experimental techniques. This can be appropriate in the science courses at the upper level of an university and certainly at the research level, but it is not necessary for teaching good science to secondary-school students and even less necessary at the basic or elementary level, where a more phenomenological approach is quite adequate in view of the concrete level of reasoning of the students.

For many experiments the precision of low-cost locally produced equipment is comparable to the precision of high-cost imported equipment and it has the advantages discussed above, including availability of spare parts and of local repairs and replacements. Moreover, it is more likely to be used because teachers and administrators are not too concerned about damage caused by students.

On the other hand, not everything can or should be done with low-cost locally produced equipment. For instance, it would be ludicrous to try to make carbon resistors locally; they would cost several times more to make than to buy from manufacturers that produce them in huge quantities. Good quality oscilloscopes, microscopes, telescopes, pH meters, etc., should be bought in moderate quantities and should be part of a well-balanced equipment policy in any education system.

Universities could produce video recordings of demonstrations and measurements needing sophisticated equipment and schools should then be provided with video cassette recorders and television sets. These audio-visual aids should supplement, but not substitute for, experiments done by the students themselves.

The particular blend of low-, medium- and high-cost equipment used in an education system should be a judicious decision. Incorporating low-cost materials and equipment does not ensure that the lack of good judgement often displayed in the selection of imported equipment will disappear. It is essential that the selection of equipment should have a close relationship with the curriculum and with the pre- and in-service training of the teachers.

Many equipment manufacturers make exaggerated claims, in their catalogues and advertisements, about the quality and precision of their goods. It could be helpful to have an independent evaluation of equipment carried out by international panels with the support of Unesco and non-governmental organizations. Teachers and administrators would then have valuable technical information to guide them in their decisions about imported equipment and a point of comparison for the low-cost equipment produced in the country.

Let us now look at some aspects with negative implications. The selection of low-cost equipment to be constructed in a country implies a lengthy process. Prototypes have to be adapted to be built with parts and materials available in the local market and in this process critical parts or complete sets which need to be imported must be identified and their timely supply ensured.

The selection process should be carried out for the curriculum of the country as a whole, and the materials, equipment and experiments should be chosen to help in achieving the general goals of the curriculum and the specific objectives of the syllabus of each subject.

To carry out this complex task, a team of specialists from several fields of knowledge would need to co-operate across interdisciplinary lines and frequently across inter-institutional lines, since quite often these specialists have to be chosen from different institutions: the Ministry of Education, teacher-training colleges or institutes, universities, technical schools or colleges, etc.

It is not an easy task to obtain the enthusiastic collaboration needed from a number of institutions and individuals. To keep such a team working in harmony for the long period of time required to produce tangible results, powerful and skilful leadership is needed. Also necessary are long-term and stable education policies, but unfortunately in many countries policies change drastically when the government changes and sometimes when the Minister of Education is changed. From the political point of view, it takes a long time before the government or the minister in charge can show the benefits of low-cost equipment in a political campaign. Obtaining loans from abroad or grants from international organizations to import large quantities of equipment, which can then be given to schools at special ceremonies with good press coverage, yields short-term political benefits. It matters very little whether or not the equipment is properly used, whether it turns out to be more expensive than it should have been, or whether it fits well with the national curriculum.

These difficulties have hindered a wider use of low-cost equipment around the world. There might be people with the training and the desire to lead the innovation, but they might not find adequate political support. Inter-institutional jealousy might be high and the close co-operation needed be not obtained. Thus there are many political and organizational problems to be solved before a large-scale national programme can be successfully launched.

## Exchange of information

Original and ingenious ideas are not very common in any field of human endeavour and science and technology teaching equipment is no exception. It is, therefore, important that the designs of equipment and the ideas for experiments be widely diffused. Limitations of funds and import and export restrictions make it difficult to distribute prototypes widely, but technical information about designs and experiments should be distributed to all countries.

Unesco has produced a number of publications which are distributed to all Member States from Headquarters or to some Member States from the regional offices. These are a valuable source of information about designs and experiments. Some Unesco publications in this field are listed at the end of this chapter. Several non-governmental organizations also help in this important aspect.

In 1984 Unesco established an International Network for Information in Science and Technology Education (INISTE) with 137 members from 111 countries, which is still expanding. Through this network, information is reaching more centres, universities and teachers throughout the world.

At the national level the designs and experiments have to be scrutinized to select those that better fit the curriculum and adapt those selected to local conditions. In this process prototypes should be built and tested before sending the information to the teachers. A few designs and experiments covering only a few topics of the curriculum do not do much good. An effort must be made to have a wide coverage of the topics included in the curriculum and in the syllabus for each grade of the school system.

It is not essential that publications such as those of Unesco should reach every schoolteacher if there is the national selection process mentioned above, but it is quite important to have teacher participation in this process. The process should be quite open-minded and care should be taken to encourage the participants to produce their own designs and experiments and to publish the results obtained. It would be quite useful to institute national and international contests with prizes and distinctions awarded for new and ingenious designs and experiments.

## Some examples

In this section some examples are presented and discussed in detail. This seems better than providing a list of things that could be done, without making comments about specific items in the list. Detailed designs and lists of low-cost equipment can be found in some of the publications cited at the end of this chapter.

The first example refers to the development of equipment and experiments in acoustics. The problem was to design and construct equipment suitable to show the modes of vibration (fundamental tone and overtones) of open and closed tubes, as well as the phenomena of interference and beats with sound waves.

The modes of vibration of resonant tubes are usually demonstrated with Kundt's tube. A very light fine powder is placed inside the tube and the vibration is induced by a tuning fork, whose power output is very small. Tuning forks that give a pure tone of predetermined frequency are difficult to make; therefore they are expensive and several are needed to display the fundamental and first harmonics of each tube. The special light powder comes with the equipment and works well in a very dry environment, but tends to go lumpy in the humid environment of tropical countries, where air conditioning is not available in most schools.

Keeping the idea of Kundt's tube, another approach was tried to replace tuning forks. An audio oscillator was used to drive a small speaker (8 or 10 cm in diameter) at a pure frequency and the speaker excited the resonance in the tubes. Powdered styrofoam (from discarded packing material) was placed inside the tubes. The power output of the speaker (3–4 watts) is much greater than that of a tuning fork. The modes of vibration could be clearly and even spectacularly shown. The frequencies of the different harmonics and the length of the tubes could then be used to calculate the speed of sound, with good agreement with the accepted value.

With two speakers driven by the same oscillator and separated by 0.6 to 1 metre, maxima and minima produced by interference could be clearly hear when the observer walked in front of the speakers along a line parallel to them. With two audio oscillators and two speakers, excited at slightly different frequencies, loud beats could be heard and use of an oscillator in tuning then discussed.

But audio oscillators are expensive and it is out of the question to imagine that each school could have even one, let alone several, to allow students to do the experiments themselves. How could the cost be reduced? Teachers and students have easy access to cassette tape-recorders, particularly the portable type. A number of pure tones from the audio oscillator were recorded on tape and that recording was reproduced on standard audio cassettes. The speakers were mounted in small wooden boxes with a support to hold the resonant tubes. The acoustical experiments could now be carried out by the students at a reasonable cost, much smaller than that necessitated by the purchase of a collection of tuning forks of different frequencies, since quite a few tones (each lasting one to two minutes) can be recorded on a single cassette.

The information about these experiments can be easily disseminated by means of a technical file card, reproduced in Appendix 1 from a bulletin published by Unesco's Regional Office for Education in Latin America and the Caribbean (OREALC) since 1981, and later adopted for another publication (Unesco, 1985). On a single sheet of paper, the specifications and purposes of the prototype are summarized in sufficient detail to enable it to be reproduced in another country.

The second example refers to equipment for general laboratory use: a small power supply and an electronic voltmeter. Both illustrate how to use integrated circuits to build low-cost apparatus. The details of the design and construction are presented in the form of technical file cards, but let us first briefly discuss the motivation to design and build these particular prototypes. It has been customary to use dry cells or rechargeable batteries as power supplies in many school applications. In many developing countries the batteries are supplied initially to the school as part of an imported consignment of equipment for many schools. When the batteries or cells are used up, quite often there is no budget to replace them and the experiments are no longer carried out.

A small and reliable power supply can be built with a transformer, an integrated circuit that regulates the voltage output and a few diodes, resistors and capacitors. As can be seen in the corresponding technical file card, the cost of the parts, plus box and assemblage is of the order of $15 to obtain a good power supply capable of producing up to 1.5 amperes, adequate for many applications to simple circuits (see Appendix 2).

The third file card (Appendix 3) contains the design of a simple voltmeter which uses an integrated circuit that compares an internal reference voltage with the voltage to be measured. The design uses batteries, but these could be replaced by a small power supply similar to the one discussed above. In the construction a scale has to be built and calibrated to read the voltage directly. The voltmeter can be buit for about $5 whereas an analogue instrument (moving-coil type) costs $25–30. Also, the low-cost voltmeter has a very high input impedance, much larger than can be obtained with a moving-coil instrument.

As discussed above, building equipment using modern electronic devices could be a good exercise after the students (in their final years of secondary school) have been familiarized with diodes and transistors, and have studied the properties of the particular integrated circuits to be used in the building of meters and power supplies.

Simple circuits for building an electronic chronometer, a thermometer, a pH meter and other measuring instruments are readily available in the literature and could be built and tried out by teachers and students, after suitable training of the teachers and if the integrated circuits and appropriate tools are supplied to the schools.

# References

UNESCO. 1983. *New Trends in School Science Equipment*. Paris, Unesco.

——. 1985. *Low Cost Equipment for Science and Technology Education*. Paris, Unesco. (Unesco doc. ED.85/WS/60.)

# Further reading

OREALC (UNESCO REGIONAL OFFICE FOR EDUCATION IN LATIN AMERICA AND THE CARIBBEAN). *Boletín de fichas técnicas sobre equipo de bajo costo para enseñanza de las ciencias/Bulletin of Technical File Cards on Low Cost Equipment for Science Teaching*, No. 1. Santiago, Chile, OREALC, 1981. (Bulletins Nos. 1–6 1981–86, are available in English and Spanish).

——. *Improvisations in Science. A Handbook for Teachers*. Santiago, Chile, OREALC, 1985. Available in English and Spanish.)

UNESCO. *New Unesco Source Book for Science Teaching*. Paris, Unesco, 1973.

——. *Unesco Handbook for Science Teachers*. Paris/London/New York, Unesco/Heinemann/Unipub, 1980.

# Appendix 1

FILE CARD FOR EXCHANGE OF INFORMATION ON PROTOTYPES
OF LOW COST EQUIPMENT FOR SCIENCE TEACHING

1. NAME OF THE PROTOTYPE
ACOUSTIC RESONANCE

2. PURPOSE OF THE EQUIPMENT DESIGNED
ACOUSTIC RESONANCE IN OPEN AND CLOSED ORGAN PIPES

3. AUTHOR (S) : ADAPTED BY RAMIRO TOBON R.

4. REFEREE : MULTITALLER DE MATERIALES DIDACTICOS

5. INSTITUTION/ADDRESS MULTITALLER DE MATERIALES DIDACTICOS-UNIVALLE-CALI-COL.

6. DRAWINGS OF THE PROTOTYPE, MATERIALS AND PERFORMANCE

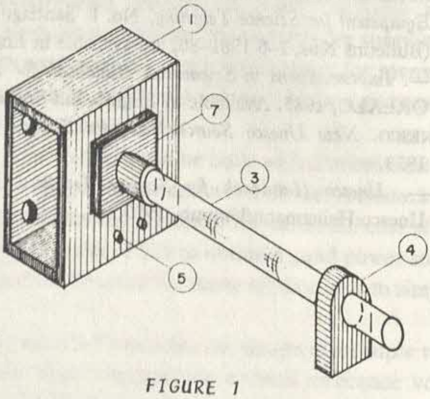


FIGURE 1

OPERATION:

*The sinusoidal signal from an oscillator is amplified by an audio tape recorder to drive the speaker. The acoustic resonance phenomena is observed for certain frequencies in open and closed pipes. The resonance condition is detected by the strong vibration of a light styrofoam or dry cork powder uniformly spread over the transparent pipe. To make easier the operation a wide range of frequencies are recorded in a cassette that is then played in the tape recorder to do the experiment instead of the oscillator. The cassette may be reproduced for other equipment sets.*

MATERIALS

| No. | NAME OF THE PART | QTY | MATERIALS | COMMENTS |
|---|---|---|---|---|
| 1 | Box of support of speaker | 1 | Wood, 1 cm thick. | |
| 2 | Speaker | 1 | 4" speaker, current use. | |
| 3 | Transparent pipes | 3 | 30, 45, 60 cm. of glass of plastic | |
| 4 | Pipe support | 1 | Wood | |
| 5 | Female jacks | 2 | To plug the tape recorder | |
| 6 | Styrofoam powder | | fine powder, dry. | |

**7. DETAILS OF CONSTRUCTION** (Drawings parts, perspectives, other details)

The dimensions of the box that houses the speaker are not critical. A suitable size hole must be made to couple the loudspeaker vibrations to the pipes. For long pipes it is necessary to build a pipe support (4). See Figures 1 and 2 for details.

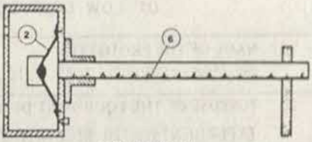


FIGURE 2

The loudspeaker is fixed with screws and it is connected by wires with the input jacks. It is convenient to protect the speaker with a fine steel mesh or with a cloth, placed on the surface of the box next to the pipe holder. The second support (4) must be of suitable size to hold the pipe horizontally. The pipes are cut out of tubes made of glass 1 - 1.5" in diameter or made of transparent plastic. The set of pipes has 30, 45 and 60 cm. pipes. The total length of the pipe is from the vertex of the speaker cone to the open end of the pipe.

In an experiment the following data was obtained with open pipes:

| Pipe Length (cm) | Frequency (Hz) | Wavelength (cm) | $f.\lambda$ (m/s) |
|---|---|---|---|
| 61.5 | 233 | 123 | 286 |
| | 490 | 61.5 | 301 |
| 46.8 | 343 | 93.6 | 321 |
| | 704 | 46.8 | 329 |
| 31.8 | 476 | 63.6 | 303 |
| | 938 | 31.8 | 298 |

Note: Without the pipes a pair of speakers can be used to do an interference experiment with sound waves with the set up shown in Figure 3.

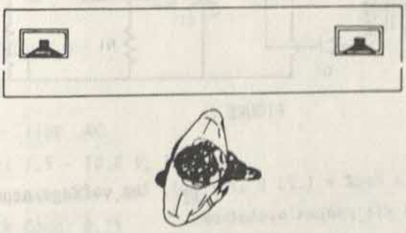


FIGURE 3

**8. APPROXIMATE LOCAL COST IN US$ :** 8.00

**9. FORM OF PRESENTATION**
Equipment distributed assembled ready for use.

**10. USE OF THE EQUIPMENT**
Acoustic resonance in open and closed pipes. Interference experiments

**11. COMMENTS**
REFERENCE: Tobón Ramiro, Gutiérrez Edmundo, MODULO DE ONDAS, Guía del Alumno, pags. 37-41, Guía del Profesor, pags. 108-122, Multitaller de Materiales Didácticos, 1982.

# Appendix 2

FILE CARD FOR EXCHANGE OF INFORMATION ON PROTOTYPES
OF LOW COST EQUIPMENT FOR SCIENCE TEACHING

1. NAME OF THE PROTOTYPE
DC POWER SUPPLY. 1.25 - 10.0 V DC., 1.5A.

2. PURPOSE OF THE EQUIPMENT DESIGNED
EXPERIMENTS WITH ELECTRIC CIRCUITS

3. AUTHOR (S) : CARLOS J. DIAZ

4. REFEREE : MULTITALLER DE MATERIALES DIDACTICOS

5. INSTITUTION/ADDRESS MULTITALLER DE MATERIALES DIDACTICOS - UNIVALLE-CALI-COL.

6. DRAWINGS OF THE PROTOTYPE, MATERIALS AND PERFORMANCE

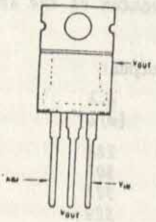


FIGURE 1

*The variable voltage power supply is based on the integrated circuit LM 317T. This is a variable voltage regulator with a range 1.2V - 37V with a maximum capacity of 1.5A. The pin configuration is shown in Fig. 1.*

*The circuit of the power supply is very simple and its schematic diagram is given in Fig. 2.*

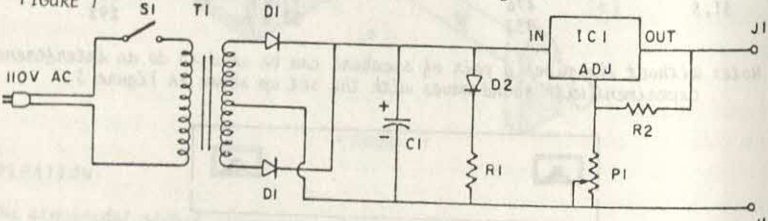


FIGURE 2

*Operation.*

*The output voltage is* $V_{out} = 1.25\ V\ (1 + \frac{P1}{R2})$. *The voltage regulator requires* $V_{out} - V_{in}\quad 3V$, *for its proper operation.*

MATERIALS AND PARTS.

| | |
|---|---|
| IC1 | Voltage Regulator LM 317T |
| D1 | 3A Diodes (2) |
| D2 | LED (Light Emitting Diode) |
| T1 | Transformer 110V/9-0-9V, 2A. |
| C1 | Electrolythic Capacitor 4700 μF/25V |
| R1, R2 | Resistors 470Ω 1/2W. |
| P1 | Potentiometer 5KΩ with switch |
| J1 | Insulated Jacks (2). |
| | Standard plug, duplex connecting cord, knob, aluminum box. |

**7. DETAILS OF CONSTRUCTION** (Drawings parts, perspectives, other details)

The power supply is mounted in an aluminum box 10 x 8 x 15 cm with a removable top.

In the front panel of the face of the box, holes are drilled to fix the potentiometer P1, the LED D2, that indicates if the supply is ON and the two jacks (J1) for the output of the power supply

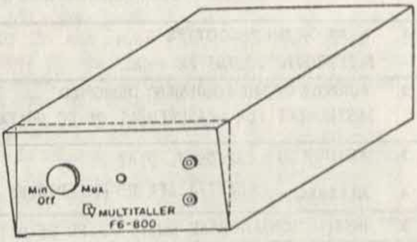


FIGURE 3

Inside the box the transformer is fixed with two screws and nuts, the regulator IC must be electrically insulated from the box, but in good thermal contact, the other components are soldered on a printed circuit or on a standard printed card, and this card is fixed to the botton of the box.

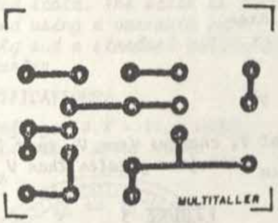


FIGURE 4

In the prototype developed, it was not necessary to use capacitors in the input and output of the regulator. It was tested during several hours, giving 6V and 1.5A without any problem.

SPECIFICATIONS.

Input voltage: 110V AC

Output Voltage: 1.5 - 10.0 V, DC

Maximum output current: 1.5A

Regulation with load: 0.1%

**8. APPROXIMATE LOCAL COST IN US$ :** 15.00

**9. FORM OF PRESENTATION**
Power supply ready for use by students.

**10. USE OF THE EQUIPMENT**
To provide power for experiments with electrical circuits.

**11. COMMENTS**

# Appendix 3

FILE CARD FOR EXCHANGE OF INFORMATION ON PROTOTYPES
OF LOW COST EQUIPMENT FOR SCIENCE TEACHING

1. NAME OF THE PROTOTYPE
ELECTRONIC VOLTMETER - DC.

2. PURPOSE OF THE EQUIPMENT DESIGNED
INSTRUMENT FOR MEASUREMENT OF DC VOLTAGES: 1.0 - 11.0 V.

3. AUTHOR (S) : CARLOS J. DIAZ

4. REFEREE : MULTITALLER DE MATERIALES DIDACTICOS

5. INSTITUTION/ADDRESS MULTITALLER DE MATERIALES DIDACTICOS - UNIV. VALLE-CALI

6. DRAWINGS OF THE PROTOTYPE, MATERIALS AND PERFORMANCE

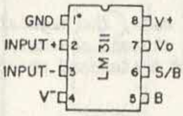


FIGURE 1

*The voltmeter is built with the Integrated Circuit LM 311 N (Voltage Comparator). The pin configuration is shown in Figure 1.*

*Figure 2 shows the symbol of the comparator. The voltage comparator compares the input signal $V_{in}$ with a reference signal $V_{ref}$.*

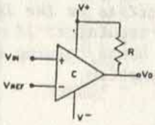


FIGURE 2

*The operation conditions are:*

*If* $V_{ref} < V_{in}$, *then* $V_0 = V^+$

*If* $V_{ref} > V_{in}$, *then* $V_0 = V^-$

*That is, the output signal* $V_0$ *changes from* $V^+$ *to* $V^-$ $(= 0V)$ *when the input signal* $V_{in}$ *goes from greater than* $V_{ref}$ *to lower than* $V_{ref}$.

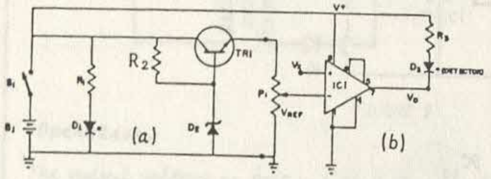


FIGURE 3

ELECTRONIC VOLTMETER - D.C.

(a) Reference voltage power supply.

(b) Voltage Comparator.

*The measurement of an unknown voltage* $V_x$ *is made comparing it with a known reference voltage* $V_{ref}$ *(Figure 3a).* $V_{ref}$ *is varied by* $P_1$ *until it reaches the unknown voltage value.*

MATERIALS.

*Semiconductors*

IC1 Voltage Comparator LM311N
TR1 2N3904, BC108C, Transistor npn
D1 Light emitting diode, green
D2 BZV88 or equivalent, Zener 13 V.
D3 Light emitting diode, red (detector)

*Potentiometer*

P1, Carbon 5 KΩ, linear

*Resistors*

R1, R3 : 1.5 K
R2 : 560 Ω

*Miscellaneous:*

B1 : 2 batteries 9V., S1 SPST switch, Base for IC1, 8 pins, Knob, Indicator (9) made of tranparent plexiglass 1/16". 2 Plugs (female), cables, Aluminum box 16 x 12 x 6 cm.

7. DETAILS OF CONSTRUCTION (Drawings parts, perspectives, other details)

*The voltmeter is mounted in an aluminum box (1) of 16 x 12 x 6 cm with removable cover (2), The switch S1 ON/OFF (3), the diode D1 (4) (shows when the instrument is ON), the detector diode D3 (5) the input jacks (red and black) (6) and the potentiometer P1 (7) are placed on the cover plate. Around the potentiometer is placed a circle of white paper to engrave the scale (8) and the knob which is glued to the indicator (9). See Figure 4.*

*The other components are mounted on a plastic card of 6 x 4 cm. making the holes to place the components. An 8-pin base must be used for the LM311 comparator. The card is fixed to the box by a piece of aluminum plate bended in L and the conections are made with a thin cable (#24). Figure 5 shows the details of the scale and in Figure 6 the details of the indicator (9) are shown*

*OPERATION:*

*If* $V_{ref} < V_x$, *then* $V_0 = V^+$ *and the detection diode D3 is Off. If* $V_{ref}$ *increases (by means of P1) in such a way that becomes:* $V_{ref} > V_x$, *then* $V_0 = 0$ *and D3 is ON. In the transition position the voltage is read in a previously calibrated scale. The scale is calibrated using a variable power supply and a standard calibrated voltmeter.*

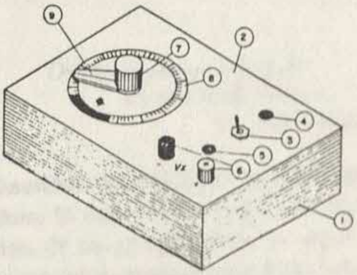


FIGURE 4

*SPECIFICATIONS:*

*DC Voltage: 0.8 - 11.2 Volts.*
*Sensitivity: ± 0.1 volt.*

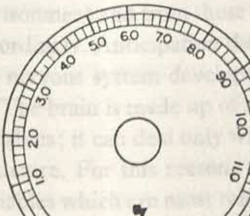


FIGURE 5

FIGURE 6

8. APPROXIMATE LOCAL COST IN US$ : *5.00*

9. FORM OF PRESENTATION
*Design and instructions distributed for its construction.*

10. USE OF THE EQUIPMENT
*Voltage meter for electricity experiments*

11. COMMENTS
*High input impedance voltmeter. Connect the right unknown voltage polarity when using for best results.*

# *Microworld–the role of the computer in science and technology education*

### George Marx

## Models

> *Our brain always anticipates.*
> *We live in the future.*
> Sir John Eccles

Real nature, each piece of material, is inexhaustible. In scientific slang, the material world has infinitely many degrees of freedom. In this world, struggle goes on for survival. The outcome is natural selection. If an animal is able to sense its environment and from these observations to anticipate coming events, it can behave accordingly. Anticipation therefore has a high selective value. This is why and how the nervous system developed.

The brain is made up of a finite number of neural cells; it can handle only a few variables; it can deal only with a few degrees of freedom out of the infinitely many in nature. For this reason, the brain must restrict itself to the interplay of a few variables which are most relevant for the animal; it has to make a simplified model of the environment. As etiologists say: the fundamental function of the nervous system is the development and utilization of these models. The capability of making predictions with the longest range has made man the king of animals.

The most far-reaching models are scientific. The history of science is the history of its models. With the concept of space (geometry, statics), man has renounced the pursuit of changes in time in order to be able to explore shapes. The celestial spheres of the geocentric world picture reflected the astronomical observations made by the naked eye. Concepts of point mass, rigid body, trajectory and reversible motion focused physicists' attention only on the minimum number of degrees of freedom. The linear model universe of Hooke, Ohm and Fourier sacrificed the interplay among various degrees of freedom in favour of mathematical simplicity. The analytical functions have renounced jumps and catastrophes, the differential equations have excluded chance, in order to be able to calculate the

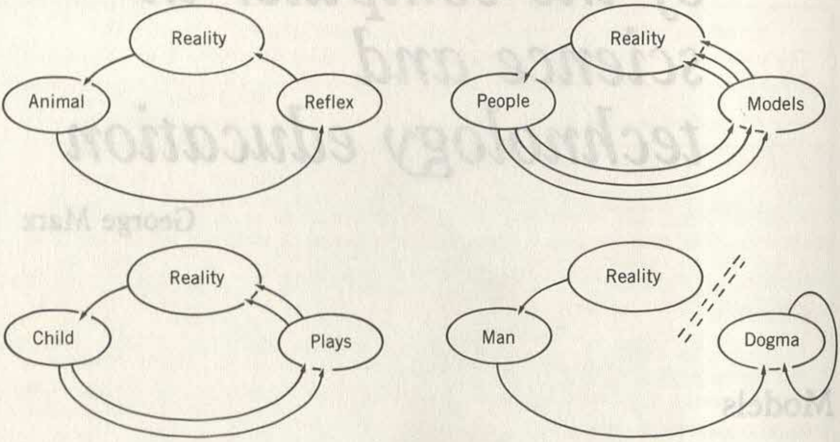


FIG. 1.

coming turn of events. Ideas such as the indivisible atom, unchangeable chemical elements, invariable biological species, ether and elastic lines of force have tried to reduce the infinite richness of nature to the vision of a more restricted clockwork universe. Favourite models of contemporary research (the quark bag, the double helix, curved and expanding space) are further examples of the struggle the human brain has to catch the 'essence' of reality by choosing more efficient (more abstract) 'relevant variables'. The antagonistic wave-particle complementarity indicates already the limits of human imagination. The separation of object and subject is one of the most magnificent tricks of our brain, enabling us to construct a rational model of the outer world. For the efficiency of this objectivity, physicists have to pay with the conceptual difficulties of observation and measurement in quantum theory: instead of certainty, they must rely on probabilities.

## Dogmas

*From shadows and images to the truth.*
Plato

If a scientific model proves itself efficient, the danger increases that it will be identified mistakenly with reality. The greatest dogmas have originated from the best models. But if we begin believing in a dogma, we have lost the control and feedback of reality. The dogma may work for awhile under fixed external conditions, but it may cease to fit a changing environment. Consequently, sooner or later, it will lose its predictive value. It will be not a motor but a brake on the quest for better understanding of our world as we struggle for survival. The geocentric world picture has been used through millennia (note the horoscope columns in today's newspapers). The static world model has survived in some schoolbooks down to the present day. Action at a distance offered a simple mathematical model for interaction; it was preferred until the voice of radio expelled it from human minds. The concept of caloric fluid was so convincing that the random motion of molecules was observed much earlier than acknowledged. The idea of absolute space, inherited from antiquity, forcefully resisted facts even in this century. We ourselves find it too difficult to give up the mental picture of trajectories within atoms. Bohr orbits are even today ikons of modern science and high technology. Copernicus, Galileo, Faraday, Boltzmann, Einstein and Heisenberg are respected as great heroes of human intellect not only because they fought and won against a traditionalist scientific establishment, but because they managed to overcome their own mental prejudices.

Even Einstein and Heisenberg claimed in their later years that their 'world equations' might be the 'ultimate models' which would explain every aspect of reality. The unavoidable dilemma of the infinite universe and finite brain was acknowledged by Niels Bohr. His complementarity principle stressed as cardinal that there is no ultimate unique model for inexhaustible matter. We have to coexist with the plurality of changing/contradicting/complementing/evolving models: science is a never-ending story! This message has not only philosophical consequences, but also political and moral implications of major educational importance.

## Computers

*The computer is a theory-machine.*
Jon Ogborn

Our brain consists of a finite number of neurons. Computers have been constructed with a finite number of memory cells. Both can handle only a finite number of variables. A computer does not give us a complete description of reality, it can offer only possible models, as does the human brain. The neural network operates by transporting rather heavy ions. A computer works with currents of electrons; thus the speed of computation can exceed that of thought by even a factor of a million. The computer elaborates the consequences of the model we invented much faster than we can. The machine may be used to run and check the consequences of alternative models under different initial conditions. It may become our most efficient tool to find out the future. It is, however, not a modern oracle. The computer does not make the future; rather, it will enable us to shape events so that the future is a more human one. The main mission of computers is not to rule us, but to assist us in making wise decisions. We have to construct our own value priorities and then we must decide which way the adventure game of our life should go.

The human race, too, has become programmed for survival. Following their ROM (the built-in genetic programme), children like to play in diverse ways. While playing, they learn by trial and error about the outside world because each play is a modelling exercise, a possible behavioural pattern. This is why children enjoy video games. 'Computers are for kids!' the slogan says. By exploiting this situation, we can make computers our powerful educational aid. Computers are 'world processors'. They not only can take us to fairy-tale worlds (to the Middle Ages, secret tombs, the Wizard's castle, outer space), but they enable us to create our own world, to escape from the real one or—preferably—to model this reality, to anticipate or to invent the future.

## Schools

*Human history is a race*
*between education and catastrophe.*
H. G. Wells

There are various commercial and educational uses and misuses of computers. Astrologists turn out horoscopes on them. Lazy teachers let the computer make up the one-question-one-answer drill exercises instead of making them up themselves. Software companies put educational texts onto floppy disks; thus page-turning is replaced by button-pushing. Software offers comfortable passivity for users and easy income for sellers. But new opportunities opened up by the arrival of microcomputers in schools enable us to solve some of the deep-rooted problems of our crisis-burdened age.

School education makes extended use of simplified models in different subjects: the Euclidean plane, the rigid body, the valence arm, invariable species, axiomatic orthography, to name but a few. To save time, school instruction usually offers one single model for one phenomenon; for comfort, the teacher presents this model as ultimate truth. This is why the world picture of traditional school is closed, complete, boring and disactivating. This strategy might have been useful in former societies, where the behavioural pattern of the good citizen seemed to be fixed for generations, but it is becoming harmful in our dynamic and ever-changing world.

There are chapters of knowledge which were considered unteachable before the computer era but which have now become accessible. After the sterile and boring arithmetic of free fall in vacuum, of sliding on a frictionless slope, of hanging on a massless rope, beyond $s=vt$ and $v=gt$ Newton's universe may come alive on the screen. We may leave the dull, straight or crazy random motion of spacecraft in space-invader games behind us and with the help of the computer we can explore and present causality in the web of phenomena. We may choose appropriate initial conditions to create the desired path and the appropriate sequence of events. Good videogames and educational programs exploit this attractive aspect by modelling ball games, motor racing (even on icy roads), space flight and moon landings. The causal mechanical world-view transformed philosophy and launched political and industrial revolutions. The full predictive power of Newtonian dynamics has become teachable to people only by the advent of microcomputers. I have a dream of creating and distributing sensible video games, based on laws of nature, with high-quality graphics and high quality excitement.

The prospects of computer aid are present in other subjects as well: revitalization of the most ancient discipline, the geometry of the Euclidean plane, by the Logo Turtle; interactive decision-making games about environmental, economic and social problems, instead of restricting education to a narrative description and explanation of the past history of the biosphere and human societies; liberation of human imagination for creative composition and design by letting the computer take over the burden of calligraphy and drawing (which may have had a decisive cultural impact in some countries, such as Japan, where the use of the full spectrum of *kanji* characters was restricted to a very small number of scholars, thus petrifying outdated social distinctions; and writing codes and constructing interfaces for the guidance of robots (instead of reading horrifying novels about the possibility of cruel machines terrorizing and exploiting humans). We are only at the beginning of the road; we do not yet see all the beauties and all the traps of the long march, but we have to go ahead. There is no turning back. Economic interests leave no other option.

We cannot discuss here all the possibilities of school computation. For illustration we select one aspect: statistics.

## Atoms

> *If, in some cataclysm, all of scientific knowledge were to be destroyed, and only one sentence passed on to the next generations of creatures, what statement would contain the most information in the fewest words? I believe it is the atomic hypothesis that 'all things are made of atoms—little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into one another.*
>
> Richard P. Feynman

Newton's universe is reversible in time. The real world is not: things wear out and break, people grow old and die. After years of university study and teaching experience, we have understood that the Second Law of Thermodynamics creates an arrow of time in the maze of phenomena. Irreversibility can be explained in a simple way if we dig deep enough below the surface. The world has an infinite number of degrees of freedom or—expressed in a simplified way—our environment is made of a huge number of atoms. Each atom obeys strict reversible laws of motion. But the aggregate of atoms behave according to statistical laws, which are already irreversible. Human beings are giant structures. In order to survive, to become so big and intelligent, we were not obliged to follow the trajectory of each individual atom (our memory and processing capability would be unable to do so). To survive, we had to answer questions like: 'How far behind is the wolf and how fast does it chase me?' or 'Which way does the wind blow today and how warm is the air?' or 'Has the sugar dissolved and is my tea sweet enough?' The macroworld is accessible and relevant to us, but it is too complex to be understood by our brains. Science has penetrated another universe, the microworld of atoms, where each object is the same (like tiny marbles) and moves in a simple way (flies straight or collides elastically). But atoms are myriad in number. Their behaviour cannot be computed exactly due to the inherent limitations of our brain and computers. However, statistical physics has shown that their random motion can explain what happens in the world of senses. We have to use a vocabulary:

| MICROWORD | MACROWORD |
|---|---|
| Number of atoms per $cm^3$ | Gas density |
| Average kinetic energy | Temperature |
| Jostle | Pressure |
| Disorder | Entropy, etc. |

The theoretical relationship between the macroworld of sensory experience and the microworld of atoms is considered to be too abstract and mathematical for most people. (Thermodynamics is generally regarded as the most difficult and least rewarding topic in university physics courses.)

Here school computers come to our help. In the world of microcomputers we can perform miracles. We can make atoms large enough to be visible as bright spots on a screen and, if we wish, we may follow the fate of a selected individual atom, a fate which is reversible in time! In this microworld hundreds of atoms jostle and if we do not focus our eyes on a single dot, but register only the light and dark regions, we experience only their statistical behaviour. (If the atoms on the screen are plentiful enough, we shall see that these coloured clouds behave in an irreversible way!) By punching a key we can jump from microworld (the atomic scenario) to macroworld (the scenario of the senses), back and forth.

By 1983 each Hungarian secondary school had been equipped with microcomputers; most were inexpensive, with low-resolution graphics. They were less impressive when they presented orbits of mass points, but these machines performed excellently at animating the corpuscular model of aggregates. This technique has turned thermodynamics (especially the Second Law) into a concrete, graphical chapter of school physics, understandable even by children at the basic operational level of thinking. For them, irreversibility has become an important and exciting characteristic of the world we live in.

Code 1 (see Appendix) depicts 500 atoms of a model crystal on the screen, all these atoms being in the ground state. (The codes are in BASIC designed for Apple-II+ or Apple-IIe computers. They can be translated easily to other microcomputers.) We may cut this crystal into two pieces, in any way we like. We can distribute any number of energy quanta to the left piece, and a different number of energy quanta to the right piece (bright squares). (For simplicity, each atom of the model crystal has only two states: ground state or excited state. This Mark-1 universe has been introduced by Atkins (1984).) The computer selects an excited atom and another ground state atom randomly: the energy quantum will be transferred from one atom to the others. The ratio of the number $N(0)$ of ground state atoms to the number $N(e)$ of the excited atoms is changing as a consequence of random energy exchanges. Press the key <T>: the computer shows the logarithm of the ratio $N(0)/N(e)$, or, for convenience, the reciprocal value of this logarithm:

$$T = \frac{1}{\log \dfrac{\mathrm{N}(0)}{\mathrm{N}(e)}}$$

As time passes, the $T$ values of the two crystal pieces level up and then they remain equal. This reminds us of the experience that, on contact, a hot solid cools down and a cold solid warms up until they reach a common temperature, which then remains steady. It is sensible to call the quantity $T$ (defined above) temperature. The formula can be rewritten as:

$$N(e) = N(0)\ \mathrm{exp.}\left(\frac{-1}{\mathrm{T}}\right)$$

If you press key <A> you may get back to the world of atoms (the screen shows the array of the 500 atoms exchanging their energy quanta randomly). If you press key <T> you see the temperatures of the two pieces of solid. The story runs parallel on two computer pages, demonstrating that the atomic view <A> and the thermometer view (the world of senses) <T> are just two faces (two models) of the same reality. In this way, students may educate their imagination: they can jump from one model to another one at will. They will learn to know how to see the atomic model behind the empirical surface of phenomena. If one of the two crystal pieces is small, the temperature $T$ will fluctuate around its steady equilibrium value. This convinces us that temperature is a bulk property: it has meaning only if the aggregate consists of very many atoms.

The number of examples is huge: we can model diffusion, evaporation, barometric distribution, Boltzmann distribution, Einstein specific heat, lattice vacancies, etc. (Marx, 1984). Here we give only one more example as an illustration from this field.

## Nuclei

*Nuclear fission is not relevant to anyone but people.*
Jay Orear

Let us take a network of squares. (These represent uranium rods.) At the beginning, let us put one coin on each square. (The coins represent neutrons.) The fate of each neutron will be decided by casting a die: if the upper face of the die shows 1, 2, 3, 4, this neutron will move up, right, down, left respectively. If the die shows 5 or 6, the neutron will be absorbed. Let us decide about each neutron in this way. The number of neutrons decreases: some of them are absorbed and some of them have escaped through the surface of the pile. The remaining neutrons produce fissions in the uranium: each neutron will be replaced by two neutrons. Then we have to start again deciding the fate of each neutron in the second generation. If the pile (the number of squares) is too small; the number of neutrons will decrease. If the number of squares is great, the number of neutrons will increase (diverging chain reaction). The goal is to find a configuration with a steady neutron number (critical nuclear reactor). We observe that criticality depends not only on the number of squares, but also on their arrangement; a compact array means less loss.

This simulation with coins and a die works only slowly. Code 2 (Appendix, page 252) offers a faster simulation. In the die play the weight of absorption was $C = 2$. On the computer, you can control the degree of absorption continuously (by typing digits 0–9). The goal is to keep the number of neutrons (the energy obtained from fissions) at a high but constant level by controlling the absorber. A word of caution: if the number of neutrons surpases 1,000, automatic control makes your model reactor disappear!

There are many reactor simulations on the market (Apple, 1982; Computers in the Curriculum Project, 1986) which can be used in the school. A real reactor cannot be brought into the classroom, but young people are interested in this controversial technology and its associated issues. You can now create yourself your own model of moderator, breeder, radioactivity, etc. (Marx, 1984).

# Animals

*Molecules did not aim at replication: they stumbled upon it.*
Peter W. Atkins

Atoms, moving according to elementary rules, can be organized into complex structures which may gain qualitatively new behavioural patterns, for example, they can reproduce themselves. Reproduction creates the phenomenon known as 'life'. This was first investigated mathematically by Von Neumann (1951). Its best known computer model is the LIFE game (Marx, 1984). By watching one single living creature, we may follow its individual fate (birth, growth, replication, ageing and death). By considering a large population of replicating organisms, we learn to understand struggle, spreading, overpopulation, stabilization, shrinking and extinction. If mutants are also tolerated in replication, diversity will be created; the struggle for life then leads to the survival of the fittest, and natural selection results in biological evolution.

These two aspects of life (individual/population) are certainly interrelated. Children love an individual pet, but the fate of the population lies far beyond their mental horizon. The second aspect, however, is gaining more and more importance on our present overpopulated and polluted globe. Most biology teachers consider population dynamics too mathematical, remote and abstract for the classroom, however.

Computer simulation can bring the individual and collective aspects together. Coloured dots may represent individuals of different species on the screen, for example, prey and predator; rabbit and fox; fish and shark. Code 3 (Appendix, page 253) gives a list for Dewdney's (1984) shark-fish universe. Here fish swim randomly and after a number of steps, determined by the player, they breed. Sharks swim around as well, and when they catch sight of a fish they swim over and eat it. After having eaten, they breed. If they cannot eat for a long period—whose length must be decided by the player—they will die of hunger. The child may focus attention on a single fish chased by the shark, but from a bird's-eye view he can also see that if the sea is overpopulated with sharks they will eat up all the available fish and be doomed to extinction! It is difficult to be a predator and survive! The goal of the game is to create a surviving fish-plus-shark universe by regulating the fitness (breeding period) of fish and the fitness (starvation capability) of the shark, beginning with appropriate population numbers.

Fundamental laws of population dynamics (the advantages of coexistence), genetics (creative interplay of chance and necessity) and evolution (the advantage of diversity in a variable environment) may be presented on the computer screen in a concrete and interesting way. Their moral implications reach far beyond the conventional frames of the school subject called biology.

# People

*In Nature we are the players,*
*but we are the cards and the stake as well.*
Teilhard de Chardin

Rabbits live on an island. A rabbit has $F$ offspring per year. (Any death is taken into account as negative birth.) The rabbit population number $P$ changes from year to year according to the equation

$$P\,(t+1) = P\,(t) + F\,P\,(t).$$

The outcome is an exponential explosion of the population:

$$P\,(t) = (1+F)^t\,\mathrm{P}\,(0)$$

if the fecundity $F$ is constant (Scenario 1).

The island, however, cannot feed an arbitrarily high number of rabbits; its supporting capacity is $E$ (e.g. $E = 100$ in Code 4). If there are only a few rabbits, they spread as in the first scenario. If their number approaches saturation, their fecundity decreases:

$$F = C\,(10 - P/E),$$

with $C$ = constant (Scenario 2). In case of overpopulation ($P{>}E$), some will die of lack of food.

$$P(t+1) = P(t) + C\,P(t)\,[1 - P(t)/E].$$

This equation is usually transformed into a differential equation

$$dP/dt = C\,P\,(1{-}P/E)$$

having a smooth analytical solution (called a logistical curve):

$$P(t) = E/[1 + A\exp(-\,Ct],$$

approaching gradually the supporting capacity $E$ of the environment. But neither schoolchildren nor rabbits have learned differential calculus. Rabbits breed in fixed seasons and so their population grows in jumps. Code 4 offers a solution of the iterative equation in finite steps. Take $P(0) = 2$, $E = 100$ and try different fecundity constants: $C = 0.2$, $0.4$, $0.6$, $0.8$ (smooth growth until saturation at

$P = E$); $C = 1.0, 1.2, 1.4, 1.6$ (overschooting $E$ and then damped oscillation converging to $P = E$), $C = 1.8, 2.0, 2.4$ (undamped oscillation of increasing amplitude and complexity); $C = 2.6, 2.8, 3.0$ (unpredictable chaotic behaviour); $C > 3$ (steep overshooting $P > E$, and then fall to $P < 0$, meaning complete extinction). Running this program in class and playing with the history (with alternative histories) of the rabbit island (corresponding to different $C$ constants) is full of tension and surprises and hints about human conditions. (The mathematical concept of chaos has been discovered by programmable calculators! If we run the same program with a slightly modified initial condition, e.g. $E = 100$, but $P(0) = 2.01$ instead of $P(0) = 2.00$, the developments will be practically the same until $C > 2.5$, but they will become completely different for $C > 2.5$. In a case of wild nonlinearity, even deterministic equations will become unstable as a result of unavoidable minute modifications of the initial conditions. The neglected molecular degrees of freedom induce irregular perturbations. Under quiet conditions, these perturbations can be neglected, but in the case of high gradients, we reach the limits of the Newtonian determinism. (Small wonder that chaos has been intensively studied by meteorologists!)

In Scenario 2, a constant supporting capacity $E = 100$ of the environment has been assumed for simplicity. But overpopulation (overburdening and pollution) of the environment decreases its supporting capacity $E$. This is shown in the Scenario 3 of Code 4 by using the coupled system of iterative equations for the two variables: $P(t)$ for people, $E(t)$ for environment:

$$P(t+1) = P(t) + C\,P(t)\left[\frac{1 - P(t)}{E(t)}\right],$$

$$E(t+1) = E(t) \text{ while } P(t) < E(t),$$

otherwise $$E(t+1) = E(t) - \frac{[P(t) - E(t)]}{2}.$$

The interplay of (human) population and (global) environment has been extensively studied by the Club of Rome (Meadows et al., 1972). In Scenario 3 we may try $C = 0.6, 0.8, 1.0, 1.2$ (gradual increase from below towards the saturation value $P = E = C = 1.4, 1.6, 1.8, 2.0$ (overpopulation degrades the environment, resulting in catastrophic decline of both $P$ and $E$). These 'limits to growth' are discussed in ecology and economics as well. The Club of Rome has warned mankind about such a danger for the twenty-first century. If no attention is paid to the coupling of individual fate to society and to its global environment, if mental inertia delays the collective reaction, if our children will not learn to understand and respect actual reality, it may prone difficult to survive the twenty-first century.

Microcomputers—as 'world processors'—are here in the school to assist us in educating young generations for understanding the interrelation between individual behaviour (of an atom, rabbit, man) and the collective history (of gas, population, society). In this way, they may become able to anticipate alternative futures, to analyse possible risks, to make appropriate decisions, to save our only planet. As is often said: the best way to foresee the future is to invent it.

# References

APPLE. 1982. *Three Mile Island.* Baltimore, Md., Muse Software. (Software.)

ATKINS, P.W. 1984. *The Second Law.* New York, Scientific American Books.

COMPUTERS IN THE CURRICULUM PROJECT. 1986. *Nuclear Reaction Simulation* (Advanced Gas Cooled Reactor). Longman Micro Software. (Software.)

DEWDNEY, A.K. 1984. Computer Recreations. Sharks and Fish Wage an Ecological War on the Toroidal Planet Wa-Tor. *Scientific American,* Vol. 251, No. 6, pp. 14–22.

MARX, G. 1984. *Games Nature Plays.* Veszprem, Hungary, National Centre for Educational Technology. (Text, with software.)

MEADOWS, D.H.; MEADOWS, D.L.; RANDERS, J.; BEHRENS, W.W. 1972. *The Limits to Growth. A Report for the Club of Rome's Project on the Predicament of Mankind.* London, Earth Island Ltd.

VON NEUMANN, J. 1951. The General and Logical Theory of Automata. In: L.A. Jeffress (ed.), *Cerebral Mechanisms in Behaviour. The Hixon Symposium,* pp. 1–31. New York, John Wiley.

# Further reading

DEAK, F.; MARX, G. Computer Models of Evolution. *Acta Physika Hungarica,* Vol. 53, 1982, p. 263.

EIGEN, M. *The Laws of the Game. How the Principles of Nature Govern Chance.* Harmondsworth, Penguin Books, 1982.

MARX, G. Some Simulations of Science. *Physics Education,* Vol. 16, 1981, pp. 152–6, 212–17.

——. Simulation Games in Science Education. *European Journal of Science Education,* Vol. 6, No. 1, 1984, pp. 31–45.

MARX, G.; TOTH, E. Models in Science Education. *Impact of Science on Society* (Unesco), Vol. 31, No. 4, 1981, pp. 389–97.

# Appendix

## *Code 1*

```
0  GOTO 280
10 E%(U,V) = 0: HCOLOR= 1: FOR I = 0 TO 4: HPLOT 8 * U + 1 + I,8 * V: HPLOT
   8 * U + 1 + I,8 * V + 4: HPLOT 8 * U + 1,8 * V + I: HPLOT 8 * U + 5,8
    * V + I: NEXT I: RETURN : REM  ATOM IN GROUND STATE
20 E%(X,Y) = 1: HCOLOR= 3: FOR I = 0 TO 4: FOR J = 0 TO 4: HPLOT 8 * X +
   1 + I,8 * Y + J: NEXT J: NEXT I: RETURN : REM  EXCITED ATOM
30  HCOLOR= 0: FOR I = 0 TO 4: FOR J = 0 TO 4: HPLOT 8 * U + 1 + I,8 * V +
   J: NEXT J: NEXT I: RETURN : REM   BLACK PAINT
40  IF L = 0 THEN TL = 0: GOTO 70
50 TL =  LOG (20 * A - L) -  LOG (L):TL =  INT (100 / TL)
60  IF TL > 150 OR TL < 0 THEN TL = 155
70  IF R = 0 THEN TR = 0: GOTO 100
80 TR =  LOG (500 - 20 * A - R) -  LOG (R):TR =  INT (100 / TR)
90  IF TR > 150 OR TR < 0 THEN TR = 159
100  PRINT TL; SPC( 6);"TEMPERATURES"; SPC( 6);TR; SPC( 3);"<A/T>?": POKE
   230,64: HCOLOR= 2: HPLOT 2 * N,159 - TL: HCOLOR= 5: HPLOT 2 * N + 1,1
   59 - TR
110  IF  PEEK ( - 16384) = 193 THEN  POKE  - 16300,0: POKE  - 16301,0
120  IF  PEEK ( - 16384) = 212 THEN  POKE  - 16299,0: POKE  - 16302,0
140 U =  INT (25 *  RND (1)):V =  INT (20 *  RND (1))
150  IF E%(U,V) = 0 THEN  GOTO 140
160 X =  INT (25 *  RND (1)):Y =  INT (20 *  RND (1))
170  IF E%(X,Y) = 1 THEN  GOTO 160
180  IF U = X AND V = Y THEN  GOTO 160
190  POKE 230,32: GOSUB 30: GOSUB 10: GOSUB 20
210  IF A > U AND A < X + 1 THEN L = L - 1:R = R + 1
220  IF A > X AND A < U + 1 THEN L = L + 1:R = R - 1
230  IF N < 139 THEN N = N + 1: GOTO 40
240  CALL  - 1059: END
280  TEXT : HOME : HTAB 15: PRINT "C R Y S T A L": HTAB 15: PRINT "-------
   --------": PRINT : PRINT
290  PRINT "THERE 500 ATOMS ALTOGETHER. EACH HAS ON-LY ONE EXCITED LEVEL
   (MARK-1 MODEL OF P.W.ATKINS).THEY EXCHANGE ENERGY QUANTA ATRANDOM. TH
   E TEMPERATURES OF THE 2 PIECESIN CONTACT ARE CALCULATED."
300  PRINT : PRINT  SPC( 6);"(TYPE <SPACE> TO CONTINUE!)"
305  IF  PEEK ( - 16384) <  > 160 THEN  GOTO 305
310  HGR2 : HGR : DIM E%(24,19)
320  FOR U = 0 TO 24: FOR V = 0 TO 19: GOSUB 10: NEXT V: NEXT U: REM  CRY
   STAL IN GROUND STATE IS DRAWN
330  FOR I = 0 TO 10: PRINT 1: NEXT I: PRINT : PRINT : PRINT
340  INPUT "HERE ARE 500 ATOMS ALTOGETHER.           HOW MANY PERCENTAGE S
   HOULD BE SEPERATED?(GIVE INTEGER MULTIPLE OF 4!) ";A
350 A =  INT (A / 4): IF A > 25 THEN  GOTO 340
360  HCOLOR= 1: FOR I = 0 TO 18: FOR J = 0 TO 2: HPLOT 8 * A - 1,5 + 8 *
   I + J: NEXT J: NEXT I: REM   SEPARATING LINE
370  PRINT "HOW MANY QUANTA FOR ";20 * A;" ATOMS(<";7 * A;")": INPUT L
380  IF L = 0 THEN  GOTO 450
400  HCOLOR= 3: FOR K = 1 TO L
410 X =  INT (A *  RND (1)):Y =  INT (20 *  RND (1))
420  IF E%(X,Y) = 1 THEN  GOTO 410
430  GOSUB 20: NEXT K
450  PRINT "HOW MANY QUANTA FOR ";500 - 20 * A;" ATOMS?(";225 - 10 * A;")
   ": INPUT R
460 E = R + L: REM  THE TOTAL ENERGY E IS CONSTANT
470  IF E = 0 THEN  PRINT "TL=0"; SPC( 20);"TR=0": FOR Q = 0 TO 3000: NEXT
   Q: GOTO 00
480  IF R = 0 THEN  GOTO 540
490  FOR K = 1 TO R
500 X = A +  INT ((25 - A) *  RND (1)):Y =  INT (20 *  RND (1))
510  IF E%(X,Y) = 1 THEN  GOTO 500
520  GOSUB 20: NEXT .K
540  PRINT "ATOMIC VIEW <A> OR TEMPERATURE <T> ?"
550  POKE 230,64: HCOLOR= 1. HPLOT 0,159 TO 279,159
560  POKE  - 16368.0: PRINT : GOTO 40
```

## Code 2

```
0  TEXT : HOME : HTAB 15: PRINT "R E A C T O R": HTAB 15: PRINT "---------
   ------"
1  PRINT "THE SIMULATION DECIDES ABOUT THE FATE OFEACH NEUTRON BY RANDOMN
    UMBER GENERATION.THE PROBABILITY OF"
2  PRINT "     MOVING LEFT = 1/(4+C)                          MOVING RIGHT= 1/(4+
    C)                 MOVING UP    = 1/(4+C)                          MOVING D
    OWN = 1/(4+C)                   ABSORBED      = C/(4+C)."
3  PRINT "THE VALUE OF 'C'IS CONTROLLED BY YOU DU-RING THE GAME.  ONE NEU
    TRON NOT ABSORBEDAND NOT ESCAPED WILL BECOME  2 NEUTRONS"
4  PRINT "BY FISSION. THE FATE OF THE NEW NEUTRONSWILL BE DECIDED AGAIN R
    ANDOMLY.YOUR GOAL IS TO KEEP THE NEUTRON NUMBER HIGH (TO"
5  PRINT "GET MUCH ELECTRIC POWER)  BUT BELOW 1000(FOR REACTOR SAFETY).
    INVESTIGATE:  HOWDOES THE NECESSARY VALUE OF CONTROL  'C'DEPEND ON RE
    ACTOR'S SIZE AND ITS SHAPE?"
20  PRINT "HOW MANY COLUMNES,ROWS OF URANIUM RODS?"
30  INPUT "(MAX. 10,6) ";C,R: REM  REACTOR SIZE IS GIVEN
40  HOME : PRINT "N(0)=";C * R;".N= ";C * R;".TYPE 1 DIGIT FOR CONTROL=2"

70  DIM A(C + 1,R + 1),B(C + 1,R + 1)
80  INVERSE
90  FOR X = 3 TO 5 + 3 * C: VTAB 3: HTAB X: PRINT " ": VTAB 4 + 3 * R: HTAB
    X: PRINT " ": NEXT X
100  FOR Y = 3 TO 4 + 3 * R: HTAB 3: VTAB Y: PRINT " ": HTAB 5 + 3 * C: VTAB
    Y: PRINT " ": NEXT Y
110  NORMAL : REM  REACTOR SIZE IS DRAWN
120  FOR X = 1 TO C: FOR Y = 1 TO R
130 A(X,Y) = 1:B(X,Y) = 1: GOSUB 320: REM  INITIAL NEUTRONS
140  NEXT Y: NEXT X
150  CALL  - 1059: REM  WHISTLE INDICATES NEW GENERATION
160  FOR X = 1 TO C: FOR Y = 1 TO R
170 A(X,Y) = 2 * A(X,Y): NEXT Y: NEXT X: REM  FISSION DOUBLES NEUTRONS
180 Z =  PEEK ( - 16384) - 176:Z =  ABS (Z)
190  IF Z > 9 THEN Z = 2: REM  Z IS THE AMOUNT OF ABSORBER
200  IF Z < 10 THEN  HTAB 40: VTAB 1: PRINT Z
210  FOR X = 1 TO C: FOR Y = 1 TO R
220  IF A(X,Y) > 0 THEN A(X,Y) = A(X,Y) - 1: GOSUB 350: GOTO 220
230  NEXT Y: NEXT X
240 N = 0
250  FOR X = 1 TO C: FOR Y = 1 TO R
260 N = N + B(X,Y):A(X,Y) = B(X,Y):B(X,Y) = 0: GOSUB 320
270  NEXT Y: NEXT X
280  HTAB 11: VTAB 1: PRINT "    "
290  HTAB 11: VTAB 1: PRINT N
300  IF N > 999 THEN  HTAB 3: VTAB 3: INVERSE : FLASH : PRINT "TO PREVENT
    RUNAWAY EMERGENCY STOP": NORMAL : VTAB 23: FOR Q = 1 TO 50: CALL  -
   1059: NEXT Q: END
310  GOTO 150
320  HTAB 2 + 3 * X: VTAB 2 + 3 * Y: PRINT "   "
330  HTAB 2 + 3 * X: VTAB 2 + 3 * Y: PRINT A(X,Y)
340  RETURN
350 W =  INT ((4 + Z) *  RND (1)): REM  CASTING THE DIE
360  IF W = 0 THEN B(X - 1,Y) = B(X - 1,Y) + 1
370  IF W = 1 THEN B(X,Y - 1) = B(X,Y - 1) + 1
380  IF W = 2 THEN B(X + 1,Y) = B(X + 1,Y) + 1
390  IF W = 3 THEN B(X,Y + 1) = B(X,Y + 1) + 1
400  RETURN
```

## Code 3

```
0  GOTO 270: REM  SHARKS
10  IF Z = 139 OR S = 0 OR  PEEK ( - 16384) = 160 THEN  GOTO 480
20 X =  INT (5 + 30 *  RND (1)):Y =  INT (10 + 20 *  RND (1)):W =  INT (4
    *  RND (1))
30  IF O%(X,Y) = 0 THEN  GOTO 20
40 Z = T / 50:T = T + 1: IF Z =  INT (Z) THEN F%(Z) = F:S%(Z) = S: PRINT
   "(";T - 1;")"; SPC( 1);F; SPC( 24);S
50 A = X - 1: IF A = 4 THEN A = 34
60 B = Y - 1: IF B = 9 THEN B = 29
70 C = X + 1: IF C = 35 THEN C = 5
80 D = Y + 1: IF D = 30 THEN D = 10
130  IF O%(X,Y) < 0 THEN  GOTO 180
140  IF O%(A,Y) * O%(X,B) * O%(C,Y) * O%(X,D) <  > 0 THEN O%(X,Y) = O%(X,
   Y) + 1: GOTO 10
150  GOSUB 262: IF O%(U,V) <  > 0 THEN W = W + 1 - 4 * (W = 3): GOTO 150
160  IF O%(X,Y) < FT + 1 THEN  COLOR= 2: PLOT X,Y: COLOR= 15: PLOT U,V:O%
   (U,V) = O%(X,Y) + 1:O%(X,Y) = 0: GOTO 10
170  COLOR= 15: PLOT U,V:F = F + 1:O%(X,Y) = 1:O%(U,V) = 1: GOTO 10
180  IF (O%(A,Y) < 0) + (O%(X,B) < 0) + (O%(C,Y) < 0) + (O%(X,D) < 0) < 4
    THEN  GOTO 210
190  IF O%(X,Y) + ST < 0 THEN  COLOR= 2: PLOT X,Y:O%(X,Y) = 0:S = S - 1: GOTO
   10
200 O%(X,Y) = O%(X,Y) - 1: GOTO 10
210  IF (O%(A,Y) > 0) + (O%(X,B) > 0) + (O%(C,Y) > 0) + (O%(X,D) > 0) > 0
    THEN  GOTO 250
220  IF O%(X,Y) + ST < 0 THEN  COLOR= 2: PLOT X,Y:S = S - 1:O%(X,Y) = 0: GOTO
   10
230  GOSUB 262: IF O%(U,V) <  > 0 THEN W = W + 1:W = W - 4 * (W = 4): GOTO
   230
240  COLOR= 2: PLOT X,Y: COLOR= 0: PLOT U,V:O%(U,V) = O%(X,Y) - 1:O%(X,Y)
    = 0: GOTO 10
250  GOSUB 262: IF O%(U,V) < 1 THEN W = W + 1:W = W - 4 * (W = 4): GOTO 2
   50
260  COLOR= 0: PLOT U,V:F = F - 1:S = S + 1:O%(X,Y) =  - 1:O%(U,V) =  - 1
    : GOTO 10
262 U = A * (W = 0) + X * (W = 1) + C * (W = 2) + X * (W = 3):V = Y * (W =
   0) + B * (W = 1) + Y * (W = 2) + D * (W = 3): RETURN
270  TEXT : HOME : HTAB 14: VTAB 4: PRINT "S H A R K S": HTAB 14: VTAB 5:
    PRINT "-----------": PRINT : PRINT : PRINT
280  PRINT "FISH MOVE AND BREED IN THE OCEAN.": PRINT : PRINT "SHARKS MOV
   E AND EAT IN THE OCEAN."
290  PRINT : INPUT "INITIAL NUMBER OF FISH,SHARKS: ";F,S
300  IF F + S > 300 THEN  GOTO 290
310  PRINT : INPUT "TIME OF FISHBREADING,SHARKSTARVING:";FT,ST
322  PRINT : PRINT "(TO SEE POPULATION CURVES:<SPACE>)": PRINT : PRINT "C
   OLOR(1) OR BLACK/WHITE(0) SCREEN?":
324  PRINT : GET Q: PRINT : PRINT : PRINT  SPC( 8);"THIS IS THE OCEAN"
330  DIM O%(35,30),F%(279),S%(279)
340  GR : COLOR= 2: FOR X = 5 TO 34: FOR Y = 10 TO 29: PLOT X,Y: NEXT Y: NEXT
   X: COLOR= 15
350  IF F = 0 THEN  GOTO 410
360  FOR I = 0 TO F - 1
370 X =  INT (5 + 30 *  RND (1)):Y =  INT (10 + 20 *  RND (1))
380  IF O%(X,Y) > 0 THEN  GOTO 370
390  PLOT X,Y:O%(X,Y) =  INT (1 + FT *  RND (1)): NEXT I
410  COLOR= 0: IF S = 0 THEN  GOTO 10
420  FOR I = 0 TO S - 1
430 X =  INT (5 + 30 *  RND (1)):Y =  INT (10 + 20 *  RND (1))
440  IF O%(X,Y) <  > 0 THEN  GOTO 430
450  PLOT X,Y:O%(X,Y) =  - 1 *  INT (1 + ST *  RND (1)): NEXT I: GOTO 10
480  HGR : HCOLOR= 6: HPLOT 0,159 TO 279,159
485  HCOLOR= 7: FOR J = 0 TO 135: HPLOT J,158 - F%(J) / 2: HPLOT J,157 -
   F%(J) / 2: NEXT J
485  HCOLOR= 1: FOR J = 0 TO 135: HPLOT J,158 - S%(J) / 2: HPLOT J,157 -
   S%(J) / 2: NEXT J: END
```

## Code 4

```
0  TEXT : HOME : PRINT  SPC( 10);"P O P U L A T I O N": PRINT  SPC( 10);"
   ---------------------"
10  PRINT "RABBITS LIVE AND BREED ON AN ISLAND.    P IS THE NUMBER OF RAB
    BITS.T IS THE YEARF IS FECUNDITY  OF RABBITS,INITIALLY F=CE IS SUPPOR
    TING CAPACITY OF ENVIRONMENT."
20  PRINT "SCENARIO 1: RABBITS BREED WITH                         CONSTANT F
    ECUNDITY                       P(T+1)=P(T)+F*P(T)": PRINT
30  PRINT "SCENARIO 2: STABLE ENVIRONMENT                         FINITE
    CAPACITY                       F(T+1)=C*(1-P(T)/F(T))": PRINT
40  PRINT "SCENARIO 3: STABLE ENVIRONMENT                         BUT P(0) I
    NCREASED                       BY 1%": PRINT
50  INPUT "SCENARIO 4: DEGRADING ENVIRONMENT                      F=CONST IF
     P<F, OTHERWISE                F(T+1)=F(T)-(P(T)-F(T))/2 ";Q
60  PRINT : INPUT "COLOR (1) OR BLACK/WHITE (0)? ";C
90  HOME : HGR : HCOLOR= 2: HPLOT 0,150 TO 279,150
100  VTAB 22: INPUT "GIVE MULTIPLICATION RATE! C=";C
105  IF Q = 3 THEN  PRINT : PRINT "TWO POPULATIONS: WHITE AND YELLOW DOTS
   . THEIR DIFFERENCE IS DEPICTED IN   BLUE."
110 F = 100:P = 2:R = 2.02:T = 0: HCOLOR= 7
115  IF Q = 3 THEN W = P - R: IF  ABS (W) > 95 THEN W = 95 *  SGN (W)
116  IF Q = 3 THEN  HCOLOR= 6: HPLOT 2 * T,95 TO 2 * T,95 - W: HCOLOR= 7
120  IF P < 151 THEN  HPLOT 2 * T,150 - P: HPLOT 2 * T + 1,150 - P
125  IF Q = 1 THEN P = (1 + C) * P: GOTO 150
130  IF Q = 4 THEN E = E - (P > F) * (P - F) / 2
140 P = P + C * P * (F - P) / F
141  IF Q = 3 THEN R = R + C * R * (F - R) / F: HCOLOR= 5: HPLOT 2 * T +
   1,150 - R: HCOLOR= 1
150  IF P < 0 THEN  PRINT "P<0! THE POPULATION HAS DIED OUT!       TYPE <
   SPACE> FOR NEW RUN,<ESC> FOR END.": GOTO 170
160 T = T + 1: IF T < 125 THEN  GOTO 115
165  PRINT : PRINT "TYPE <SPACE> FOR NEW RUN,<ESC> FOR END."
170  IF  PEEK ( - 16384) = 160 THEN  GOTO 90
180  IF  PEEK ( - 16384) <  > 155 THEN  GOTO 170
190  END
```

# Assessment of students' learning in science education

## Geoff Giddings and Barry J. Fraser

There is little doubt in science and technology education that the teacher's assessment procedures have a potent influence on how students approach their learning, and that the public examination system similarly has a significant impact on teaching methods. Whereas Malcolm Rosier's chapter (page 271) is devoted to national monitoring of attainments in science and technology education, this chapter gives consideration to assessment in three areas that are often neglected in teachers' assessment programmes: (a) assessment of students' practical work; (b) assessment of students' attitudes to science; and (c) assessment of classroom environment.

## Assessment of practical work

Practical work is expensive in terms of equipment, facilities and teacher's time, yet most science teachers consider it essential for improving students' understanding of science concepts, their manipulative skills and their appreciation of the way in which scientific knowledge is generated and validated. However, recent reviews of research on the effectiveness of laboratory classes have cast some doubt on their efficacy (Bates, 1978; Solomon, 1980; Hofstein and Lunetta, 1982; Johnstone and Wham, 1982.) Unfortunately, because research has not been comprehensive, we simply do not know enough about the effects of laboratory instruction upon student learning and growth. There is good reason, nonetheless, to believe that laboratory activities are important in fostering understanding of certain aspects of the nature of science, intellectual and conceptual development, positive attitudes towards science, and certain problem-solving and psychomotor skills.

### *Goals of practical work*

Science teachers who genuinely want their students to develop problem-solving and laboratory skills ensure that these kinds of learning find their way into tests and other evaluation procedures. Teachers and students clearly recognize that assess-

TABLE 1. Goals for laboratory activity

| Domain | Goal |
|---|---|
| Cognitive | To promote intellectual development |
| | To enhance the learning of scientific concepts |
| | To develop problem-solving skills |
| | To develop creative thinking |
| | To increase understanding of science and scientific methods |
| Practical | To develop skills in performing science investigations |
| | To develop skills in analysing investigative data |
| | To develop skills in communicating |
| | To develop skills in working with others |
| Affective | To enhance attitudes towards science |
| | To promote positive perceptions of one's ability to understand and to affect one's environment |

*Source*: Lunetta et al., 1981.

ment procedures reflect the true goals of teachers and schools, and that many students put their best efforts in to activities that will be rewarded (Grobman, 1970). Table 1 provides a list of the diverse goals which different teachers might aim for in their laboratory teaching.

Irrespective of the teacher's particular goals, student behaviours in the science laboratory can be grouped into four broad phases of activity:

*Planning and design*: formulating questions, predicting results, formulating hypotheses to be tested and designing experimental procedures.

*Performance*: conducting the experiment, manipulating materials, making decisions about investigative technique, observing and reporting data.

*Analysis and interpretation*: processing data, explaining relationships, developing generalizations, examining the accuracy of data, outlining assumptions and limitations, and formulating new questions based on the investigation.

*Application*: making predictions for new situations, formulating hypotheses on the basis of investigative results and applying laboratory techniques to new problems (Kempa and Ward, 1975; Lunetta and Tamir, 1978).

While some of these abilities can be enhanced through other activities, the laboratory offers unique opportunities for their development.

## *Evaluation systems for the laboratory*

Systems for evaluating student activities in the laboratory can be classified into four broad categories: (a) written reports; (b) test items; (c) laboratory practical examinations; and (d) observational assessment (Lunetta et al., 1981). Evaluation of students' written laboratory reports is one of the most common assessment methods traditionally used. But grading reports is often subjective because neatness, writing skills, 'volume' and degree of 'completion', for example, can bias evaluation (Tobin, 1986). Moreover, the written report does not provide direct information about a student's skill in manipulating equipment observing, organizing and performing an investigation efficiently (Eglen and Kempa, 1974; Whittaker, 1974; Doran and Dietrich, 1980). Consequently, sole-dependence on laboratory reports in evaluating laboratory activity can lead students to copy from one another or to invent data. Consideration should be given to ways of using student reports more creatively (for example allowing students to refer to their laboratory notebooks during quizzes or tests). By adding this element of realism, such regular use of notebooks can have dramatic effects on student preparation.

Paper-and-pencil test items designed to assess knowledge of the techniques and principles underlying laboratory procedures can be prepared, though this is often time-consuming. Test items also can assess student skills in the planning, design, analysis and application phases of laboratory activity (Hofstein and Giddings, 1980), but written test items should not be used exclusively as the basis for evaluation. For example, students can be asked to read a temperature or measure a length from a scale printed on the test, but their ability to do so with real equipment might involve other skills not measured on the written test.

Some science teachers give students so-called practical examinations to assess acquisition of manipulative skills, observational abilities and more complex problem-solving and process skills. For example, Tamir (1974) outlined an inquiry-orientated laboratory examination and marking scheme which was designed to measure students' ability to solve novel problems in the laboratory. Marking was done according to a predetermined key of weighted scores for skills of manipulation, self-reliance, communication, experimental design and measuring. At several points during the examination, the examiner would mark students' answers and provide continuation cue cards.

One way of organizing a practical examination makes use of the 'station' technique (pupils circulating around a number of small experiments or practical tasks usually on a timed basis). Robinson (1969), for example, designed a laboratory practical examination consisting of twenty one-and-a-half-minute experimental stations involving measuring, identifying, selecting or computing. Harden and Cairncross (1980), after using the stations approach to assess the practical skills of medical students, claimed that it was valid, reliable and practicable where large numbers of students were involved. Bryce and Robertson (1985), in their excellent review, reported the successful use of this approach in the national implementation of practical assessment for certification purposes.

Because each of the three evaluation systems mentioned thus far has serious limitations regarding the breadth of skills that can be measured, more continuous systems of observation and assessment have been developed, especially in the

TABLE 2. Observational assessment criteria

| Skill area | Criteria | Score |
|---|---|---|
| A. Planning and design | Able to present a perceptive plan for investigation. Plan is clear, concise and complete. Able to discuss plan for experiment critically. | 9–10 |
| | Good, well-presented plan, but needs some modification. Understands overall approach to problem. | 7–8 |
| | Plan is good, but some help is needed. Not a very critical approach to problem. | 5–6 |
| | Poor, ineffective plan, needing considerable modification. Does not consider important constraints and variables. | 3–4 |
| | Little idea of how to tackle the problem. Much help needed. | 1–2 |
| | No opportunity to use these skills. | |
| B. Manipulative skills, conduct of the experiment | Good general ability to carry out full range of skills. Appreciates precision of apparatus. Quantitative results within expected range. Can carry out plan in a reasonable time, modifying it creatively and effectively when appropriate. | 9–10 |

United Kingdom (Bryce et al., 1983) and Israel (Cohen et al., 1978). Continuous assessment on several occasions throughout the year is necessary to cover adequately the variety of tasks and techniques which comprise a total programme of practical work and to reduce the likelihood of chance success or failure. Also, with a greater involvement in the continuous assessment of practical skills, the teacher is likely to develop a greater awareness of the scope and objectives of laboratory work and to identify student strengths that might otherwise not have been reflected in more conventional assessments. Perhaps the most powerful point is that, if teachers wish to encourage the development of practical skills, then any assessment system must be seen by the students to acknowledge this aim.

In observational assessment, the teacher unobtrusively observes and rates each student during normal laboratory activities. Observations can be recorded over an extended period of time or during a single laboratory activity. Teachers also can

| Skill area | Criteria | Score |
|---|---|---|
| C. Observations and recording of data | Correct observations specified; unexpected results noted. Errors and possible inaccuracies are not ignored. All relevant information accurately recorded in an appropriate form. | 9–10 |
| D. Interpretations of data and the experiment | Good appreciation of data, appreciation of error and limitations of experiment. Knows when to search for additional information. Good analytical approach. Good appreciation of scale of experiment. Ability to calculate accurately results from experimental data. Good written and oral appreciation of results and variables. Good ability to make inferences from data, to suggest explanations and to relate the whole practical experience to particular problems. | |
| E. Responsibility | Self-reliant, able to work with little supervision. Willing to tackle problems. Can work as part of a team as well as on own. Safety conscious. Willing to help in running of laboratory if asked. Consistent and perseveres. Tackles practical work with enthusiasm. | |

*Note:* Adapted with modifications from publications of the Joint Matriculation Board and the University of London Examination Board. In the interest of brevity, full details on scoring criteria are presented only in Skill Area A: Planning and design.

*Source*: Joint Matriculation Board, 1979; University of London, 1977.

distribute skill checklists to their students and ask them to rate themselves after each laboratory session or at the completion of a unit. The teacher can then review the students' assessments and indicate agreement or disagreement.

Table 2 presents possible criteria and rating scales for observational assessment, based upon work in the United Kingdom. It outlines criteria for the assessment of behaviours in planning and design, manipulative skills, conduct of experiments, observations and recording of data, interpretations of data from the experiment, and responsibility, initiative and work habits.

From this evidence, there appear to be clear benefits accruing from the use of checklists in many areas of practical science assessment, although it should be noted that detailed checklists could be unsuitable instruments for the assessment of some aspects of laboratory activity (Bryce and Robertson, 1985). Certainly, to advocate the use of checklists by a teacher during an informal, on-going experimental session must take into account not only the difficulties incurred in operating several checklists at one time, but also the common school practice of pupils working in pairs or small groups. Any procedure adopted must offer the possibility of an objective and valid assessment of each individual pupil within the class.

In summary, it has been maintained in this section that for many years science educators have argued in favour of the importance of the laboratory in science teaching and learning. While laboratory experiences alone will not promote all the goals of science teaching, they are important vehicles for attaining some of our goals. Yet teachers have generally not incorporated laboratory goals within their systems of grading and evaluation. It is also clear that many of the basic science skills have not been acquired by students doing practical work in laboratories. The development of appropriate laboratory experiences together with relevant assessment techniques appears central to making laboratory experiences in science effective, interesting and efficient. Teachers who want to help students develop by doing science should, therefore, make use of written reports, test items, practical tests and observational assessment to evaluate student performance and to promote the mastery of specific skills.

## Assessment of attitudes to science

In many countries today, the development of a positive attitude to science and the scientific enterprise is among the major aims of science teaching and the area of attitudes to science is a major research priority (Gardner, 1975; Ormerod and Duckworth, 1975; Munby, 1980; Abraham et al., 1982; Shrigley, 1983; Schibeci, 1984). While there is a considerable consensus of opinion that the promotion of favourable attitudes to science is an important aim of science education, there is confusion about what meaning should be placed on the term 'attitude to science'. Klopfer (1971), however, has alleviated the semantic problems associated with the multiple meanings attached to the term by providing a comprehensive classification scheme for science education aims in which six conceptually different categories of attitudinal aims are distinguished. These six categories, which are listed in Table 3, involve distinctions between attitudes to science and scientists (H.1), attitude to inquiry (H.2), adoption of scientific attitudes such as curiosity and open-mindedness (H.3), enjoyment of science learning experiences (H.4), interest in science apart from learning experiences (H.5) and interest in a career in science (H.6). Table 3 also shows how the scales of one particular attitude questionnaire, the Test of Science-related Attitudes (TOSRA) (Fraser, 1978, 1981*b*), provides coverage of the distinct attitude categories identified by Klopfer.

TABLE 3. Descriptive information and reliability for each scale of TOSRA

| Scale name | Klopfer (1971) classification | Sample item[1] | Alpha reliability |
|---|---|---|---|
| Social implications of science | H.1: Manifestation of favourable attitudes towards science and scientists | Scientific discoveries are doing more harm than good (–) | 0.81 |
| Normality of scientists | | Scientists usually like to go to their laboratories when they have a day off (–) | 0.72 |
| Attitude towards inquiry | H.2: Acceptance of scientific inquiry as a way of thought | I would prefer to find out why something happens by doing an experiment than by being told (+) | 0.82 |
| Adoption of scientific attitudes | H.3: Adoption of 'scientific attitudes' | I like to listen to people whose opinions are different from mine (+) | 0.67 |
| Enjoyment of science lessons | H.4: Enjoyment of science learning experiences | Science lessons bore me (–) | 0.92 |
| Leisure interest in science | H.5: Development of interests in science and science-related activities | I dislike reading newspaper articles about science (–) | 0.88 |

1. Items designated (+) are scored by allotting 5, 4, 3, 2, 1 for responses, strongly agree, agree, not sure, disagree, strongly disagree, respectively. Items designated (–) are scored in the reverse manner.

Table 3 provides the name of each of the six scales of TOSRA, the classification of the aim measured by each scale according to Klopfer's (1971) classification, and a sample item from each scale. Since category H.1, 'Manifestation of favourable attitudes towards science and scientists', embraces two somewhat different attitudes (towards science and towards scientists), TOSRA contains a separate measure of each. The 'social implications of science' scale measures one aspect of attitude towards science, namely attitude towards the social benefits and problems which accompany scientific progress. The 'normality of scientists' scale measures an aspect of attitude towards scientists, namely, an appreciation that scientists are normal people rather than the eccentrics often depicted in the mass media. The 'attitude towards inquiry' scale is similar in meaning to Category H.2 and measures students' attitudes towards scientific experimentation and inquiry as ways of obtaining information about the natural world. The 'adoption of scientific attitudes' scale is identical in meaning to Category H.3 and covers areas such as open-mindedness, willingness to revise opinions, etc. The last two scales in Table 3 are identical in meaning to categories H.4 and H.5 and are called, respectively, 'enjoyment of science lessons' and 'leisure interest in science'.

Each scale in TOSRA contains ten items of five-point Likert-response format, with the scoring direction of half the items reversed. Table 3 provides data about the internal consistency reliability (alpha coefficients) for each TOSRA scale based on the sample of 1,337 science students in Grades 7-10 from eleven different schools in Sydney, Australia.

An important feature of Likert-type items is that their intention is often obvious to the test respondent and, therefore, the possibility of students faking responses to some items cannot be completely overlooked. Consequently, like most attitude tests, TOSRA is of limited usefulness for the purpose of grading individual students because students could fake answers to improve their grades. However, as long as TOSRA is not used for grading, probably there would be little point in students faking responses and reasonable confidence could be placed in their responses. In cases where information is required about groups rather than individuals, the likelihood of faking could be further reduced by making responses anonymous.

Attitude instruments such as TOSRA can be used by teachers, curriculum evaluators or researchers to monitor student progress towards achieving attitudinal aims. Although it is possible to use TOSRA for assessing the progress of individual students, it is likely to be most useful for examining the performance of groups or classes of students (for example, in curriculum evaluation). Furthermore, as well as providing information about attitudes at a particular time, TOSRA could also be used as a pre-test and a post-test (perhap over the time of a school term or year) to obtain information about changes in attitudes. Certainly, a major advantage that TOSRA possesses over some other science attitude tests is that it yields a separate score for a number of distinct attitudinal aims instead of a single overall score.

## Assessment of classroom environment

Traditionally science teachers have tended to rely heavily and sometimes exclusively on the assessment of academic achievement as representative of the goals of the educative process. Although few responsible educators would dispute the worth of outcome measures, they cannot give a complete picture of the educational process. Moreover, because students spend up to 15,000 hours at school by the end of senior high school (Rutter et al., 1979), they certainly have a large stake in what happens to them at school and their reactions to, and perceptions of, their school experiences are significant. This section is devoted to one approach to conceptualizing, assessing and investigating what happens to students during their schooling. In particular, the main focus is upon students' and teachers' perceptions of important social and psychological aspects of the learning environments of school science classrooms.

In contrast to methods that rely on outside observers, the approach described here defines classroom environment in terms of the shared perceptions of the students and sometimes the teachers in that environment. This has the dual advantage of characterizing the class through the eyes of the actual participants and capturing data which the observer could miss or consider unimportant. Students are at a good vantage point to make judgements about classrooms because they have encountered many different learning environments and have enough time in a class to form accurate impressions. Also, even if teachers are inconsistent in their day-to-day behaviour, they usually project a consistent image of the long-standing attributes of classroom environment.

Over the previous two decades, considerable effort internationally has gone into work on the assessment and investigation of students' perceptions of psychosocial aspects of their classroom learning environment (Moos, 1979; Walberg, 1979; Fraser, 1981*a*, 1986*a*, 1986*b*). A sizeable proportion of this research has involved science classes specifically (Fraser and Walberg, 1981). These reviews show that the most frequently used classroom environment instruments have been the *Learning Environment Inventory* (Fraser et al., 1982), the *Classroom Environment Scale* (Fisher and Fraser, 1983*b*) and the *Individualized Classroom Environment Questionnaire* (Fraser, 1987). These instruments can be used to tap perceptions of either actual or preferred classroom climate among either students or teachers.

## *Example of a classroom environment instrument*

In order to clarify the nature of a typical classroom environment instrument, a copy of a short form of the Individualized Classroom Environment Questionnaire (ICEQ) is provided in the appendix to this chapter. This short twenty-five-item form, which contains only half of the items in the corresponding long form, was developed to provide a more rapid and economical assessment (Fraser, 1982). Unlike the long form, the short form does not need to make use of a separate answer sheet since all items and space for responding fit on a single page.

In order to facilitate hand scoring, the letter 'R' is included in the 'teacher use only' column to identify those items which need to be scored in the reverse direction and items are arranged in blocks and in cyclic order so that all items from the same scale are found in the same position in each block. For example, the first item in each block of five items belongs to the 'personalization' scale. Items without the letter 'R' are scored by allocating the circled number (i.e., by scoring 1, 2, 3, 4 and 5, respectively, for the responses 'almost never', 'seldom', 'sometimes', 'often' and 'very often'). Underlined items with the letter 'R' are scored in the reserve manner. Omitted or invalidly answered items are scored 3. To obtain scale totals, the five-item scores for each scale are added. The first, second, third, fourth and fifth item in each block of five, respectively, measures personalization, participation, independence, investigation and differentiation. For example, the total personalization score is obtained by adding scores for items 1, 6, 11, 16 and 21. Scale totals can be written in the spaces provided at the bottom of the questionnaire. The questionnaire illustrates how these scoring procedures were used to obtain a total of 16 for the personalization scale and a total of 12 for the differentiation scale.

For the short form of the ICEQ, scale reliabilities have been estimated for a sample of 116 Grade 8 and 9 classes in thirty-three schools in Tasmania, Australia. Using the class as the unit of analysis, reliabilities for the five scales of personalization, participation, independence, investigation and differentiation were, respectively, 0.83, 0.73, 0.70, 0.69 or 0.85 for the actual form and 0.73, 0.70, 0.75, 0.63 and 0.84 for the preferred form.

## *Applications of classroom environment instruments*

Classroom environment scales are useful in evaluating alternative curricula or new innovations in science and technology education. For example, in evaluations of Harvard Project Physics (Anderson, et al., 1969) and the Australian Science Education Project (Fraser, 1979), revealing differences were found between alternative curricula in terms of classroom climate when cognitive outcome measures showed no differences.

Interesting studies have involved comparison of students' and teachers' perceptions of actual and preferred classroom environment (Fisher and Fraser, 1983*a*). First, students preferred a more favourable classroom environment than the one that was actually present. Second, teachers perceived the classroom environment more favourably than did their students in the same classrooms. This finding that students' perceptions of the classroom differ from those of the teacher highlights the merit of teachers collecting perception data from their students.

A large number of past studies (see Fraser, 1986*a*) provides much consistent evidence that classroom environment is linked with students' outcomes. For example, in a comprehensive meta-analysis, Haertel et al. (1981) found that student learning was consistently related positively to classroom cohesiveness, satisfaction and task orientation, and related negatively to friction and disorganization. These findings have important practical implications about the ways in which science classrooms might be changed in an attempt to improve student learning.

### Improving classroom environments

It is highly desirable that the recent emphasis on research into classroom environment should have some practical application in facilitating improvements in science classrooms. A suggested approach described by Fraser (1981*c*) involves: (a) administering a classroom environment instrument twice (once to assess actual environment and once to assess preferred environment); (b) identifying discrepancies between the actual environment and that preferred by students; (c) implementing classroom strategies aimed at aligning the actual environment more closely with students' preferred environment; and (d) re-administering the climate scales in order to determine the extent to which attempts at environmental improvement were successful. It is noteworthy that recent applications of this strategy in science classes have supported the effectiveness of the strategy and attested to the potential usefulness of employing classroom environment instruments to provide science teachers with meaningful information about problem areas and a tangible basis to guide improvements in these areas (Fraser and Fisher, 1986).

The major purpose of this overview of studies of perceptions of psychosocial classroom environments is to make this exciting young research tradition more accessible to wider audiences. Given the ready availability of instruments, the salience of classroom environment, the impact of classroom environment on student outcomes and the potential of environmental assessments in guiding educational improvement, it seems crucial that researchers and teachers begin to include classroom environment instruments as part of their overall assessment system. It has been assumed that having a positive classroom environment is an educationally desirable end in its own right. Moreover, evidence presented here also clearly establishes that the nature of the classroom environment also has a potent influence on how well students achieve a range of desired educational outcomes. Consequently, science educators need not feel that they must choose between striving to achieve constructive classroom environments and attempting to enhance student achievement of cognitive and affective aims. Rather, constructive educational climates can be viewed as both means to valuable ends and as worthy ends in their own right.

## References

ABRAHAM, M.R.; RENNER, J.W.; GRANT, R.M.; WESTBROOK, S.L. 1982. Priorities for Research in Science Education. A Survey. *Journal of Research in Science Teaching*, Vol, 19, No. 8, pp. 697–704.

ANDERSON, G.J.; WALBERG, H.J.; WELCH, W.W. 1969. Curriculum Effects on the Social Climate of Learning. A New Representation of Discriminant

Functions. *American Educational Research Journal*, Vol. 6, No. 3, pp. 315–28.

BATES, G.R. 1978. The Role of the Laboratory in Secondary School Science Programs. In: M.B. Rowe (ed.), *What Research Says to the Science Teacher*. Vol. 1, pp. 55–82. Washington, D.C., National Science Teachers Association.

BRYCE, T.G.; ROBERTSON, I.J. 1985. What Can They Do? A Review of Practical Assessment in Science. *Studies in Science Education*, Vol. 12, pp. 1–24.

BRYCE T.G.; MCCALL, J.; MACGREGOR, J.; ROBERTSON, I.J.; WESTON, R.A. 1983. *Teacher's Guide: TAPS Assessment Pack*. London, Heinemann Educational Books.

COHEN, I.; BEN-ZVI, R.; HOFSTEIN, A.; SAMUELS, D. 1978. The Assessment of Practical Work in High School Chemistry Instruction. *Halaha L'Masase: Theory and Practice in Curriculum Instruction*, Vol. 2, pp. 31–43.

DORAN, R.L.; DIETRICH, M.C. 1980. Psychomotor Abilities of Science and Non-science High School Students. *Journal of Research in Science Teaching*, Vol. 17, No. 6, pp. 495–502.

EGLEN, J.R.; KEMPA, R.F. 1974. Assessing Manipulative Skills in Practical Chemistry. *School Science Review*, Vol. 56, No. 195, pp. 261–73.

FISHER, D.L.; FRASER, B.J. 1983*a*. A Comparison of Actual and Preferred Classroom Environments as Perceived by Science Teachers and Students. *Journal of Research in Science Teaching*, Vol. 20, No. 1, pp. 55–61.

——. 1983*b*. Validity and Use of Classroom Environment Scale. *Educational Evaluation and Policy Analysis*, Vol. 5, pp. 261–71.

FRASER, B.J. 1978. Development of a Test of Science-related Attitudes. *Science Education*, Vol. 62, pp. 509–15.

——. 1979. Evaluation of a Science-based Curriculum. In: H.J. Walberg (ed.), *Educational Environments and Effects: Evaluation, Policy and Productivity*, pp. 218–34. Berkeley, Calif., McCutchan.

——. 1981*a*. *Learning Environment in Curriculum Evaluation. A Review*. (Evaluation in Education Series). Oxford, Pergamon.

——. 1981*b*. *Test of Science-related Attitudes*. Melbourne, Australian Council for Educational Research.

——. 1981*c*. Using Environmental Assessment to Make Better Classrooms. *Journal of Curriculum Studies*, Vol. 13, No. 2, pp. 131–44.

——. 1982. Development of Short Forms of Several Classroom Environment Scales. *Journal of Educational Measurement*, Vol. 19, No. 3, pp. 221–7.

——. 1986*a*. *Classroom Environment*. London, Croom Helm.

——. 1986*b*. Two Decades of Research on Perceptions of Classroom Environment. In: B.J. Fraser (ed.), *The Study of Learning Environments*. Salem, Ore., Assessment Research.

——. 1987. *Individualized Classroom Environment Questionnaire*. Melbourne, Australian Council for Educational Research.

FRASER, B.J.; ANDERSON, G.J.; WALBERG, H.J. 1982. *Assessment of Learning Environments; Manual for Learning Environment Inventory (LEI) and My*

*Class Inventory (MCI)*. 3rd version. Perth, Western Australian Institute of Technology.

FRASER, B.J.; FISHER, D.L. 1986. Using Short Forms of Classroom Climate Instruments to Assess and Improve Classroom Psychosocial Environment. *Journal of Research in Science Teaching*, Vol. 23, No. 5, pp. 387–413.

FRASER, B.J.; WALBERG, H.J. 1981. Psychosocial Learning Environment in Science Classrooms. A Review of Research. *Studies in Science Education*, Vol. 8, pp. 67–92.

GARDNER, P.L. 1975. Attitudes to Science. A Review. *Studies in Science Education*, Vol. 2, pp. 1–41.

GROBMAN, H. 1970. *Developmental Curriculum Projects: Decision Points and Processes*. Itasca, Ill., Peacock Publishers.

HAERTEL, G.D.; WALBERG, H.J.; HAERTEL, E.H. 1981. Socio-psychological Environments and Learning. A Quantitative Synthesis. *British Educational Research Journal*, Vol. 7, pp. 27–36.

HARDEN, R.M.; CAIRNCROSS, R.G. 1980. Assessment of Practical Skills. The Objective Structured Practical Exam (OSPE). *Studies in Higher Education*, Vol. 5, No. 2, pp. 187–96.

HOFSTEIN, A.; GIDDINGS, G. 1980. *Trends in Assessment of Laboratory Performance in High School Science Instruction*. Science Education Center, University of Iowa. (Technical Report, No. 20.)

HOFSTEIN, A.; LUNETTA, V.N. 1982. The Role of the Laboratory in Science Teaching. Neglected Aspects of Research. *Review of Educational Research*, Vol. 52, No. 2, pp. 201–17.

JOHNSTONE, A.H.; WHAM, A.J. 1982. The Demands of Practical Work. *Education in Chemistry*, Vol. 19, No. 3, pp. 71–3.

JOINT MATRICULATION BOARD. 1979. *The Internal Assessment of Practical Skills in Chemistry*. Manchester, JMB.

KEMPA, R.F.; WARD, J.F. 1975. The Effect of Different Modes of Task Orientation on Observational Attainment in Practical Chemistry. *Journal of Research in Science Teaching*, Vol. 12, No. 1, pp. 69–76.

KLOPFER, L.E. 1971. Evaluation of Learning in Science. In: B.S. Bloom, J.T. Hastings and G.F. Madaus (eds.), *Handbook on Summative and Formative Evaluation of Student Learning*, pp. 559–641. New York, McGraw-Hill.

LUNETTA, V.N.; HOFSTEIN, A.; GIDDINGS, G.J. 1981. Evaluating Science Laboratory Skills. *The Science Teacher*, Vol. 48, No. 1, pp. 22–5.

LUNETTA, V.N.; TAMIR, P. 1978. An Analysis of Laboratory Activities in Two Modern Science Curricula: Project Physics and PSSC. Paper presented at Annual Meeting of National Association for Research in Science Teaching, Toronto, Ontario.

MOOS, R.H. 1979. *Evaluating Educational Environments. Procedures, Measures, Findings and Policy Implications*. San Francisco, Jossey-Bass.

MUNBY, H. 1980. An Evaluation of Instruments which Measure Attitudes to Science. In: C. McFadden (ed.), *World Trends in Science Education*, pp. 266–75. Halifax, Nova Scotia, Atlantic Institute of Education.

Ormerod, M.B.; Duckworth, D. 1975. *Pupils' Attitudes to Science. A Review of Research*. Windsor, NFER Publishing Co.

Robinson, J. 1969. Evaluating Laboratory Work in High School Biology. *American Biology Teacher*, Vol. 31, pp. 236–40.

Rutter, M.; Maughan, B.; Mortimore, P.; Ouston, J.; Smith, A. 1979. *Fifteen Thousand Hours. Secondary Schools and Their Effects on Children*. London, Open Books.

Schibeci, R.A. 1984. Attitudes to Science. An Update. *Studies in Science Education*, Vol. 11, pp. 26–59.

Shrigley, R.L. 1983. The Attitude Concept and Science Teaching. *Science Education*, Vol. 67, No. 4, pp. 425–42.

Solomon, J. 1980. *Teaching Children in the Laboratory*. London, Croom Helm.

Tamir, P. 1974. An Inquiry-oriented Laboratory Examination. *Journal of Educational Measurement*, Vol. 11, pp. 23–5.

Tobin, K. 1986. Secondary Science Laboratory Activities. *European Journal of Science Education*, Vol. 8, No. 2, pp. 199–211.

University of London. 1977. *Advanced Level Chemistry. Notes of Guidance and Report Form for the Optional Internal Assessment of Special Studies*. London, University of London.

Walberg, H.J. (ed.) 1979. *Educational Environments and Effects. Evaluation, Policy and Productivity*. Berkeley, Calif., McCutchan.

Whittaker, R.J. 1974. The Assessment of Practical Work. In: H.G. Mackintosh (ed.), *Techniques and Problems of Assessment*. London, Arnold.

# Appendix

## Individualized Classroom Environment Questionnaire (ICEQ). Short form

Name __________ School __________ Class __________

| Remember you are rating *actual* classroom practices | Almost never | Seldom | Some-times | Often | Very often | Teacher use only |
|---|---|---|---|---|---|---|
| 1. The teacher talks with each student. | 1 | ② | 3 | 4 | 5 | 2 |
| 2. Students give their opinions during discussions. | 1 | 2 | 3 | 4 | 5 | |
| 3. The teacher decides where students sit. | 1 | 2 | 3 | 4 | 5 | R |
| 4. Students find out the answers to questions from textbooks rather than from investigations. | 1 | 2 | 3 | 4 | 5 | R |
| 5. Different students do different work. | ① | 2 | 3 | 4 | 5 | 1 |
| 6. The teacher takes a personal interest in each student. | 1 | 2 | 3 | 4 | ⑤ | 5 |
| 7. The teacher lectures without students asking or answering questions. | 1 | 2 | 3 | 4 | 5 | R |
| 8. Students choose their partners for group work. | 1 | 2 | 3 | 4 | 5 | |
| 9. Students carry out investigations to test ideas. | 1 | 2 | 3 | 4 | 5 | |
| 10. All students in the class do the same work at the same time. | 1 | ② | 3 | 4 | 5 | R 4 |
| 11. The teacher is unfriendly to students. | 1 | ② | 3 | 4 | 5 | R 4 |
| 12. Students' ideas and suggestions are used during classroom discussion. | 1 | 2 | 3 | 4 | 5 | |
| 13. Students are told how to behave in the classroom. | 1 | 2 | 3 | 4 | 5 | R |
| 14. Students carry out investigations to answer questions coming from class discussions. | 1 | 2 | 3 | 4 | 5 | |
| 15. Different students use different books, equipment and materials. | 1 | 2 | 3 | 4 | 5 | 3 |

| Remember you are rating *actual* classroom practices | Almost never | Seldom | Some-times | Often | Very often | Teacher use only |
|---|---|---|---|---|---|---|
| 16. The teacher helps each student who is having trouble with the work. | 1 | 2 | ③ | 4 | 5 | 3 |
| 17. Students ask the teacher questions. | 1 | 2 | 3 | 4 | 5 | ___ |
| 18. The teacher decides which students should work together. | 1 | 2 | 3 | 4 | 5 | R ___ |
| 19. Students explain the meanings of statements, diagrams and graphs. | 1 | 2 | 3 | 4 | 5 | ___ |
| 20. Students who work faster than others move on to the next topic. | 1 | ② | 3 | 4 | ⑤ | 3 |
| 21. The teacher considers students' feelings. | 1 | ② | 3 | 4 | 5 | 2 |
| 22. There is classroom discussion. | 1 | 2 | 3 | 4 | 5 | ___ |
| 23. The teacher decides how much movement and talk there should be in the classroom. | 1 | 2 | 3 | 4 | 5 | R ___ |
| 24. Students carry out investigations to answer questions which puzzle them. | 1 | 2 | 3 | 4 | 5 | ___ |
| 25. The same teaching aid (e.g., blackboard or overhead projector) is used for all students in the class. | 1 | 2 | 3 | 4 | ⑤ | R 1 |
|  | Almost never | Seldom | Some-times | Often | Very often |  |

# *Assessment of students' learning in science and technology in national and international studies*

Malcolm J. Rosier

This chapter discusses some aspects of the assessment of students' learning in science and technology in large-scale studies at the national and international levels. The basic theme is that the assessment of learning at these levels, for the purpose of making comparisons between schools, regions and countries, must allow for the differences in science curricula covered by the students and other relevant student background characteristics.

It is obvious that not all students cover the same curriculum. Even in the education systems of countries where the science curriculum is defined at the central level, there are variations in what is actually dealt with in individual classrooms. Variation in curricular content is greater in education systems where the responsibility for curricular development is vested at the level of the school district or individual school. The first part of the chapter deals with the measurement of curriculum and achievement. The second part discusses comparisons of achievement that take account of curricular differences.

The specific context for the discussion in this chapter is provided by the Second International Science Study (SISS).[1] This is a large study undertaken to provide an overview of science education worldwide. The study is being conducted under the auspices of the International Association for the Evaluation of Educational Achievement (IEA), a non-governmental association of educational research institutes. The study, which started in 1981, is built on earlier IEA work in this area (Comber and Keeves, 1973).

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[1] Further information about the SISS may be obtained from Dr Malcolm J. Rosier, International Co-ordinator, SISS International Centre, Australian Council for Educational Research, PO Box 210, Hawthorn, Victoria 3122, Australia.

## Populations and samples

The study is being carried out in twenty-five education systems (countries) which encompass a range of levels of national development. Three target populations have been defined for the study. Population 1 basically involves students at the 10-year-old (Year 5) level; Population 2 involves students at the 14-year-old (Year 9) level; and Population 3 involves science students at the final-year secondary-school level, usually Year 12. For each population in each education system a large sample of students took part in a testing programme.[1]

## International and national components

Any international study of achievement in science, or a national study where there are different education systems within the country, must make allowances for the different conditions of learning in the various systems, which includes differences in science curricula. The strategy adopted by SISS to cope with this variability was to incorporate both international and national components.

In order to provide a common thread across the various systems, international 'core' components were developed, to be included in the testing programme in all the participating education systems. For example, a common set of international science tests was developed to measure science achievement and a common set of questions was prepared to obtain information about background characteristics of students in the testing programmes.

At the same time, individual systems were encouraged to elaborate on these core components by adding additional test items which would reflect aspects of the national curriculum not covered by the international tests and by including questions about the background characteristics of students of particular relevance to their systems.

## Stages of the curriculum

The process of measuring curriculum and achievement is founded in the idea that there are three sequential stages in the examination of a curriculum: (a) the intended curriculum; (b) the implemented curriculum; and (c) the achieved curriculum.

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[1] The education systems involved in the study are: Australia, Canada (both English- and French-speaking), China, Finland, Ghana, Hong Kong, Hungary, Israel, Italy, Japan, the Republic of Korea, Mexico, the Netherlands, Nigeria, Norway, Papua New Guinea, the Philippines, Poland, Singapore, Sweden, Thailand, the United Kingdom (England and Wales), the United States and Zimbabwe. Additional information about the populations and samples is given in other SISS publications.

## *Intended curriculum*

The first stage of the curriculum sequence is the intended curriculum. For this study, the curriculum is defined as 'all the experiences for learning which are planned and organized by the school' (Whitfield, 1971, p. 2). This definition of the curriculum implies that planning and organizing are undertaken and recorded in statements that can be examined and analysed.

In most systems, the intended curriculum is defined at the level of the Ministry of Education or other authority in charge of the education system, which may be the country as a whole in a highly centralized system (such as that of Japan), or an individual school board in a decentralized system (such as that of the United States). Indeed, in some systems the curriculum may be defined at the level of the individual school or even the individual teacher.

There were two stages in the analysis of the intended curriculum across the systems taking part in SISS. The first stage involved the preparation of a standardized classification system for the description of the content of a science curriculum. At the second stage, ratings were assigned by each system to indicate the extent to which the content areas in the class were covered by the students in that system.

The classification system for science content contains fifty-seven categories, and is based on the one presented by Klopfer (1971). There are four sections in the classification, reflecting the traditional areas of earth science, biology, chemistry and physics. It was recognized that these traditional areas may not adequately reflect the scope of science curricula that attempted to relate students' learning in science classrooms to their practical experiences in their own town or village. A set of variant science-content areas was therefore defined to cover areas such as technology, rural science and health science. Taken together, the classification systems for the traditional and variant science-content areas cover the majority of topics that are included in science curricula.

In each of the systems in the study, a group of curriculum experts assigned numerical ratings to the content areas on a scale of 0 to 3, where 0 indicated that the topic was not covered in the curriculum, 1 indicated that it had a low level of coverage in the curriculum, 2 a medium level and 3 a high level.

As an example, Table 1 sets out ratings for ten countries at the Population 2 (Year 9) level for one content area from each of earth science, biology, chemistry and physics. The ratings for solar system are generally high, although they are low in two countries. The ratings for evolution and periodic system display variability across countries, while the ratings for forces are high in all countries.

TABLE 1. Content analysis ratings

| Content category | Solar system | Evolution | Periodic system | Forces |
|---|---|---|---|---|
| Australia | 2 | 1 | 1 | 2 |
| Finland | 2 | 1 | 2 | 3 |
| Hungary | 3 | 3 | 3 | 3 |
| Israel | 2 | 2 | 2 | 3 |
| Japan | 3 | 3 | 0 | 3 |
| Netherlands | 2 | 2 | 1 | 3 |
| Papua New Guinea | 3 | 0 | 0 | 3 |
| Philippines | 1 | 0 | 3 | 2 |
| Poland | 3 | 1 | 1 | 3 |
| Singapore | 0 | 3 | 0 | 3 |

From the curriculum ratings supplied by the participating systems, it was possible to identify the main areas of curriculum content which were common to the majority of the systems. This information was used to guide the selection of science test items, so that more items were included in the international core tests to cover areas where there were higher levels of curriculum content coverage.

This process also helped the systems themselves to identify content areas that were regarded as important in their systems but were not given high priority in the international curriculum consensus. This meant that each individual system was able to use a combination of international and national science test items to develop a testing programme to assess students' learning of the content of the science curriculum for that system.

For each item in a test there is a corresponding content area rating for each country. It was therefore possible to construct a content score for each test which reflected the coverage of the content areas for that country.

## *Implemented curriculum*

The second stage in the sequence is the implemented curriculum, which has its locus at the level of the individual classroom. It is the task of the individual teacher to intepret the intended curriculum, translating it into a set of learning experiences which or she deems to be appropriate for the particular group of students in the class.

It is appropriate that the measurement of the implemented curriculum take place at the level of the science classroom. For the science study, the implemented curriculum is measured by means of ratings supplied by the teachers of the students in the sample. For each item in the science tests, the science teachers in each school rated the extent to which the group of students from that school taking part in the testing programme had had the opportunity to learn the content of the curriculum reflected by the item. These opportunity-to-learn (OTL) ratings can be converted to percentages for each item, and also to produce an opportunity score for the test as a whole.

### *Achieved curriculum*

The final stage of the curriculum sequence is the achieved curriculum. This refers to the extent to which individual students have internalized the science-learning experiences that were planned and organized for them. This is measured by means of the science tests completed by the students in the sample, from which a science score for each student is calculated.

## Relationships between curriculum and achievement

Relationships between curriculum and achievement may be demonstrated at the level of individual items. Figure 1 shows, for one of the countries in the study (Australia), the graph of opportunity ratings for the thirty items in the main

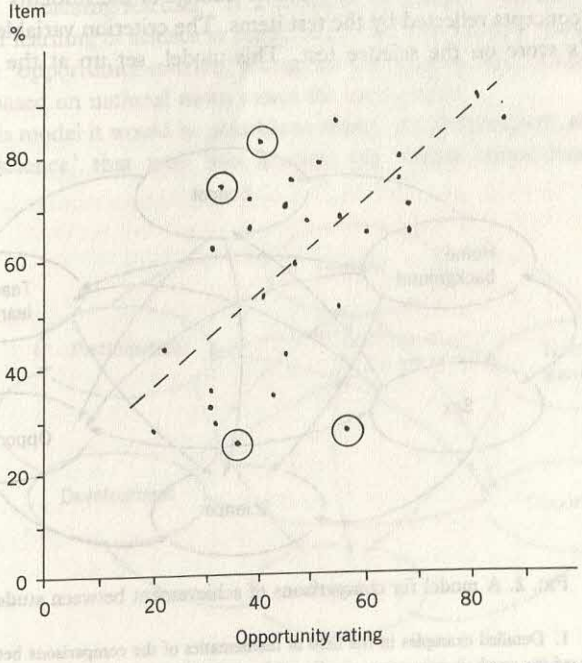

FIG. 1. Opportunity ratings versus percentage correct for items in Science Test 2M.

Population 2 science test versus the percentage of correct responses for each of the items.

There is a consistent relationship between the two dimensions as indicated by a correlation of 0.59. This presentation reveals, however, some items (circled) where there is a disparity between the teachers' ratings and the students' performance.

## Explanatory models of achievement

The simple graphs, however, merely provide an introduction to the explanation of achievement in terms of the two earlier stages of the curriculum sequence. For a more complete explanation, it is necessary to resort to statistical analyses based on causal models.1

For example, the model shown in Figure 2 contains several sets of variables that will be used in SISS to explain differences between students with respect to their science achievement. 'Home background' and 'sex' are variables that measure factors applying from the earliest stage of the students' learning experiences. 'School' measures characteristics of the school environment. 'Teaching/learning' measures characteristics of the classroom in which science learning for that student takes place. The level of coverage of the curriculum by the student is measured by 'opportunity', which is based on the teachers' ratings of the students' opportunity to learn the concepts reflected by the test items. The criterion variable 'science' is the student's score on the science test. This model, set up at the level of the

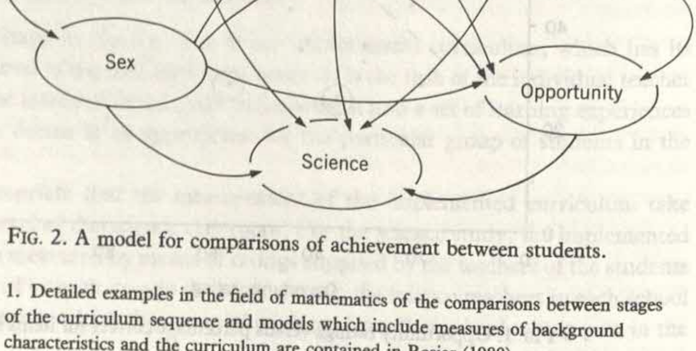

FIG. 2. A model for comparisons of achievement between students.

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1. Detailed examples in the field of mathematics of the comparisons between stages of the curriculum sequence and models which include measures of background characteristics and the curriculum are contained in Rosier (1980).

individual student, cannot include a measure of the intended curriculum, since this information is collected at the level of the education system.

By using such models, it is possible to identify the direct effects on the criterion of 'opportunity' and other factors in the model, and also to identify the indirect effects of the various factors.

The regression coefficients calculated in the process of estimating the model may be used to obtain a 'predicted' or 'expected' criterion score for each student which takes into account the background characteristics of the students and the science curriculum that the student has covered. Comparisons may then be based on the expected scores, which make an allowance for the conditions of learning, rather than on the actual scores.

The above model can also be adapted to measure differences between schools, where the data entered into the model are at the level of the school. For example, the 'Science' variable would consist of the school mean score on the science test.

A similar model, as shown in Figure 3, can be used to make comparisons between countries. In this case the variables in the model are measured at the level of the country. 'Development' is a measure of the level of national development of the country. 'Participation' is a measure of the percentage of the population at school and studying science. 'Content' is included as a measure of the intended curriculum. 'Teaching/learning' is a measure of average characteristics of the teaching and learning of science in the system. The 'opportunity' variable is based on the mean 'opportunity-to-learn' ratings for the country. The 'science' criterion variable is based on national mean scores for the country.

From this model it would be possible to obtain, for each country, an 'expected' score for 'science' that took into account the science curriculum and other

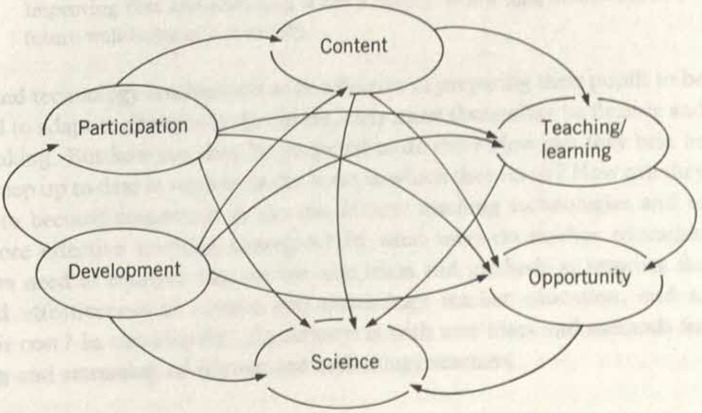

FIG. 3. A model for comparisons of achievement between education systems.

characteristics of the students in the country. The comparison of expected scores for countries is fairer and more meaningful than the direct comparison of actual test scores, which would favour those countries where the test items are closer to the work covered in their science curricula.

## Conclusion

Any assessment of students' learning which goes beyond the specific curriculum taught to a small group of students must allow for differences in the learning experiences of the students. This chapter has provided an introduction to some of the techniques being used to produce 'fair' comparisons in SISS, in the hope that the techniques will be useful in other large-scale studies.

## References

COMBER, L. C.; KEEVES, J. P. 1973. *Science Education in Nineteen Countries: An Empirical Study.* Stockholm/New York, Almquist & Wiksell/John Wiley. (International Studies in Evaluation, 1.)

KLOPFER, L. E. 1971. Evaluation of Learning in Science. In: B.S. Bloom, J.T. Hastings and G.F. Madaus (eds.), *Handbook on Formative and Summative Evaluation of Student Learning*, pp. 559–641. New York, McGraw-Hill.

ROSIER, M.J. 1980. *Changes in Secondary School Mathematics in Australia 1964–1978.* Hawthorn, Australian Council for Educational Research.

WHITFIELD, R.C. (ed.). 1971. *Disciplines of the Curriculum.* London, McGraw-Hill.

# *New methods for training and retraining science and technology teachers*

### Colin Power

## Introduction

Since the 1950s two quite distinct societal demands have been placed on science and technology education. The first is a demand for specialists with the expertise needed within the work-force. The second and more recent is a demand that all young people be helped to gain a better understanding of the nature of science and technology and their impact on daily life. As a recent Royal Society (1985, p. 1) publication put it:

> Everybody needs some understanding of science, its accomplishments and limitations, whether or not they are themselves scientists or engineers. Improving that understanding is not a luxury: it is a vital investment in the future well-being of our society.

If science and technology teachers are to be effective in preparing their pupils to be flexible and to adapt to changes in the future, they must themselves be flexible and forward looking. But how can they be prepared to do this? How can they best be helped to keep up to date in content in the areas in which they teach? How can they be helped to become competent in the use of new teaching technologies and to develop more effective teaching strategies? In what ways do teacher education programmes need to change? Can we use new ideas and methods to improve the quality and effectiveness of science and technology teacher education, and to reduce their cost? In this chapter, the concern is with new ideas and methods for the training and retraining of science and technology teachers.

## Impact of technological change on education structures and programmes

The transformations of the work-force associated with technological change have had a significant impact on education systems. Industrial, scientific and technological revolutions have been, in part, responsible for the extension of adolescence and the creation of mass systems of schooling. The current 'technotronic' revolution has increased levels of youth unemployment, education participation rates and the shortage of science and technology teachers. Changes in science and new ideas about science education have led to at least three major science-curriculum reform movements. Biology, chemistry and physics courses have been transformed, new specialist areas (such as computer science) added to the curriculum and radically different science, technology and society courses are being developed.

Not only are the new information technologies having a profound effect on science and technology curricula, but they also create exciting possibilities for helping children learn and keeping teachers up-to-date. The technotronic revolution is also affecting the way we think about learning. Education has increasingly come to be seen as a lifelong process and is being planned as such by the more adaptive corporations and education systems. One of the keys to our thinking about teacher education from now on must be to view it as occurring across the professional continuum.

## Recruitment into science and technology teaching

Associated with technological revolutions are rapid changes in the work-force. These, in turn, have meant that there are areas of science and technology education where there is a surplus of graduates, while in others there are grave shortages. Improving the quality of teaching demands an adequate recruitment pool and a flexible system for shifts in demand. Whether a country will have enough qualified teachers depends on the number of people with appropriate qualifications and their perceptions of the worthwhileness of teaching as a career.

Unfortunately, we hear too often that the best science students do not enter teaching, despite the long-standing shortage of science and technology teachers. Governments are insisting that schools place more emphasis on science and technology so that pupils can competently and creatively use them, but often fail to set up structures and policies which ensure an adequate supply of science and technology teachers or do anything to prevent the loss of our best teachers. There are few effective links between the education and the employment sectors, and few established mechanisms for ensuring that up-to-date information about new discoveries, new technologies and changes in the job market are available to those responsible for training science and technology teachers (Institute of Manpower

Studies, 1984). With the development of computer data bases, the technology for providing a better information base for planning exists.

Hawley (1986) reviewed the likely effects of twenty-three policies on recruitment and retention of teachers, and concluded that merit pay and regulatory policies are less likely to be effective than policies aimed at strengthening the profession. In addition, we could do more to attract graduates with experience in the applied sciences and technology into teaching and to tap the pool of teachers not at present teaching but who might be retrained as science and technology teachers.

## Selection for science and technology pre-service courses

Lanier and Little (1986) suggest that one of the major threats to teacher flexibility and effectiveness is that 'too many lows' have been allowed to enter and successfully exit from professional training programmes. A recent study of science-teacher education programmes in Australia (Owen et al., 1985) revealed that no institution requires a full secondary-school education in science and mathematics as a prerequisite for entry into an elementary-school teacher-education programme, and that many of those selected had dropped science early in their schooling. That many students enter and leave elementary-school teacher education programmes with little understanding of science and a strong aversion to teaching it must lead us to question existing policies.

The school science background and attitudes of entrants to secondary-school science-teacher education programmes are less of a problem. The difficulties lie in enlarging the recruitment pool and filtering out those unlikely to be effective in the classroom. The evidence suggests that, as far as possible, self-selection should be the rule during the course supplemented by assessments based on performance. Such self-selection and assessment procedures require teacher-education courses so designed that the student is involved in typical professional activities; adequate measures of the competencies to be developed in pre-service programmes; and the progressive weeding out of students with low levels of academic performance, commitment and competence in teaching. One promising strategy for improving the selection and counselling process has been developed at the University of New Hampshire (Egbert, 1985).

## Pre-service programmes

Given the analysis of research carried out by Sweitzer and Anderson (1983), no one could argue that pre-service programmes are unnecessary. Nevertheless, there is a wide gap between the outcomes of most programmes and what new teachers, school administrators and critics believe should be done. However, remarkably little is known about what is being done in pre-service science and technology programmes or the effectiveness of alternative strategies.

In the Australian colleges surveyed by Owen et al. (1985), students were required to study some science as part of their general studies programme or professional studies. The mean percentage of course time allocated to science in elementary-level programmes was under 5 per cent. In all colleges, science lecturers reported that the time allocated was not sufficient for most students to develop any real understanding of science or competence in teaching it. There are also wide variations in the emphasis in secondary programmes given to specialist studies in science on the one hand and professional studies on the other (for example, in the United States the proportion devoted to the former varies between 30 and 80 percent).

The study by Owen et al. (1985) revealed that low emphasis was given in the pre-service course to the development of the teacher's own understanding of basic scientific concepts and of how children explain the natural world, as well as to ways of catering for individual differences within a group activity in science and evaluating student progress in science. All these were seen to be extremely important by new teachers. Those interested in alternative frameworks have found that a significant proportion of teachers in both developed and developing countries share the conceptions of science held by children. For example, Ameh and Gunstone (1986) estimate that more than half of the Nigerian science teachers in their sample held views on the rusting of metal which were unscientific. New approaches to training science teachers building on work such as the Learning in Science Project at the University of Waikato, New Zeeland, are being introduced into a number of pre-service programmes (Osborne and Freyberg, 1985).

Most upper-secondary-school teacher-education programmes begin with three to four years of training in one or more of the major disciplines (biology, mathematics, etc.) as part of a science degree. Few graduates entering one-year professional programmes have undertaken any serious study of an area of technology (engineering, computing, etc.), applied science (health science, agricultural science, etc.), integrated studies (environmental science, etc.), or the philosophy, history, politics or sociology of science, mathematics or technology. Given that a significant proportion of science graduates will seek employment as teachers or in government, it would seem important for governments to encourage and support the development of the study and teaching of science and society courses in universities and colleges.

It is important to recognize that most university degree courses generally equip students with the knowledge needed to undertake basic research or to teach in a given discipline at upper secondary level, but do not provide preparation or experience of the kind needed to effectively teach all components of an integrated science, technology and society programme. As a result, few students on graduation can readily apply their knowledge to the solution of community problems, are aware of how the knowledge and skills they have acquired are utilized in industry, or are sensitive to the language and perceptual difficulties, the conceptions of science held commonly by their pupils and the potential conflicts between Western science and traditional ideas in non-Western societies. Moreover, most biology graduates show glaring deficiencies in the physical sciences and technology, and most physical science graduates have limited backgrounds in biology and the earth sciences.

It is important that teacher-education programmes ensure that potential teachers have sufficient breadth in science, technology and society generally, and depth in some area, to be both confident and effective. The research on teacher education suggests that some concurrent programmes provide too superficial a general education in science and technology for their graduates to be any more than novices (Lanier and Little, 1986). Of course, there are some very good concurrent programmes, but some pre-service courses are taught by teacher educators who themselves are in need of up-dating. The short duration and the dominance of separate methods (chemistry, physics etc.) in most end-on programmes means that they provide less than an adequate initial professional preparation for the teaching of science, technology and society programmes.

As indicated in the introductory section of this chapter, there is evidence that a marked shift in the intended outcomes of science education has been taking place over the past decade or so. However, in many pre-service programmes there has been no discernible comparable change in teacher training (ASTA, 1984). The new approaches to science and technology education do demand new roles of the teacher and the teacher educator; and as such they demand the systematic treatment of a range of topics and issues, the development of new professional competencies and the provision of experiences not normally included in current pre-service programmes.

In real life, problems are typically complex, interrelated and contextualized. Teaching integrated science, technology and society programmes demands that knowledge, ideas and techniques from a variety of areas be thrown into the melting pot, fused together and brought to bear on a set of problems. The difficulty is that few science graduates have experience in working as part of an interdisciplinary team on a significant community or industrial problem and few have sufficient understanding of other disciplines to see beyond their own. In addition, they often seem unaware that a simple translation of their scientific knowledge in the explanation of everyday phenomena and to applied problems is not always possible.

(see Prout, 1985). Universities and colleges will need to begin to tackle the problems created by the narrowness and rarified nature of the typical science degree and to act on recommendations such as those put forward by Power (1986).

A critical component in the preparation of teachers is the methods-curriculum study component of their course. It goes without saying that such courses should seek to develop a clear understanding of, and commitment to, the values and objectives of science, technology and society education, and provide the learning experiences necessary to translate curricular materials into effective programmes. In part, this will involve helping students to a reorientation of existing knowledge bases in, say, physics and biology to the teaching of a unit on, say, the problems of noise pollution. Materials such as the Unesco *Environmental Education: Module for Pre-service Training of Science Teachers and Supervisors for Secondary Schools* (Jacobson, 1986) are particularly useful. But in too many institutions, the wealth of new research-based ideas, materials and tools being produced is being ignored (Power, 1984).

Even under ideal conditions in developed countries, well-intended internal reforms of teacher-education programmes may founder, and new ideas, teacher-training methods and materials (for example, interaction analysis, microteaching, Science Teacher Education Project, etc.) may spread quickly, only to wither away. Estimates of responses to new ideas in teacher education suggest that most pre-service courses (perhaps more than 80 per cent) have yet to respond adequately to the challenges posed by changes in science, technology and science-education research. It is not merely that teacher-education programmes are often slow to adopt promising new methods imported from elsewhere or too quick to jump on bandwagons but, more importantly, teacher educators have difficulty finding time to redevelop their own programmes and to create indigenous solutions. Too rarely we read of innovations in teacher education such as the Vacation Learning Camp organized at Singapore's Institute of Education and work carried out by the Institute for the Promotion of Teaching Science and Technology (IPST) on the development and implementation of low-cost experiments in Thailand. Even quite small innovation grants have proved useful in stimulating change.

Programmes are being developed which can easily be used in equipping student teachers with competence in the use of new technologies. For example, the Computer Literacy Project and the Microelectronics Education Programme in the United Kingdom have aimed at ensuring that teachers and teacher educators play their part in helping to prepare children for life in a society where new technologies are commonplace and pervasive. The Regional Center for Educational Innovation and Technology (INNOTECH) has developed self-instructional materials in using new instructional technologies for teacher-education programmes in South-East Asia. Of course, not all of the new strategies in teacher education advocated by innovators are likely to be effective or readily transferable. What is important is that we reflect on the problems and critically assess alternatives in our own situation. Studies of alternative methods of teaching at the higher education level reveal support for some aspects of the Keller plan and competency-based teacher-education approaches in the acquisition of knowledge and skills (Dunkin and Barnes, 1986). The evidence points to the importance of small units, mastery requirements, visually based instruction using videotapes, school experience in controlled settings, feedback and review in acquiring specific science and technology competencies (but not self-pacing and behavioural objectives). More recently, programmes have begun to include strategy analysis (consisting of an analysis of teaching models, peer teaching, analysis and performance feedback) to help pre-service teachers to adopt models appropriate to activity-orientated science, technology and society programmes.

In the view of most new teachers, the practicuum is the most valuable part of the pre-service programme. The rationale for teaching practice is that prospective teachers need frequent contacts with schools so that their understanding of the teaching-learning process and teaching competence can grow hand in hand. It is assumed that school personnel share with the staff of pre-service programmes a common purpose and interest in helping beginners to develop into competent and committed science and technology teachers, and that an effective working partnership between the college staff and supervising teachers exists. Yet evidence often points to a contrary situation: few institutions can boast of either a well-designed total programme of practicuum elements integrated with methods and foundation courses, or a true partnership with schools for the benefit of students. Many of the promising developments in the area of school-based pre-service programmes and internship have fallen by the wayside as resources dried up. Nevertheless, some interesting innovatory programmes, materials and supervision training programmes are available.

The research on teaching indicates that effective instruction involves selecting (from a larger repertoire) and orchestrating those strategies, methods and materials that are appropriate to the context and to the teacher's goals, rather than mastering and consistently applying a few generic teaching skills (Brophy and Good, 1986). Having developed a set of science-teaching competencies, teacher-education programmes must help students to make sound professional decisions about their use in a range of teaching contexts. Successful adaptation to the demands encountered in science, technology and society learning settings (school and beyond) is more often accomplished through the co-ordination of abilities and appropriate knowledge than through the capacity to utilize disembodied skills on demand. It is the connections between subject, context and professional procedural knowledge which are important in effective teaching. Unfortunately there has been a long tradition of treating these as if they were separate, as if teaching skills and methods were content and context free, and as if learning content was tantamount to learning how to teach it.

## Induction of teachers

No matter how excellent a pre-service programme may be, it can never fully prepare its graduates for all the tasks and problems that occur in the range of teaching contexts encountered by new teachers. If professional development is to proceed beyond the pre-service phase, resources and effort must be directed towards helping beginners to master their new roles and responsibilities. Tisher et al. (1979) found that the Tasmanian system of new-teacher counsellors boosted confidence, helped beginners to manage key teaching tasks and helped prevent resignations. Induction programmes should provide information about the policies, programmes and community of the school, and ensure that new teachers are provided with appropriate assistance and feedback.

## Continuing education of teachers

Science and practical-arts teachers, and education systems in general, have not responded adequately to the changes set in motion by the 'technotronic' revolution. Curriculum reforms have tended to flounder because inadequate attention has been given to the professional development needs of teachers. Many science and technology teachers have had little or no in-service education since entering teaching, despite the increased need arising from an ageing profession, changes in science curricula, the development of new information technologies and the new roles demanded of teachers.

By professional development we imply more than equipping teachers with the knowledge and skills needed to implement new programmes. For professionals are not technicians trained to follow set routines. Continuous development implies an orderly progression to increasing higher levels of expertise as a teacher and as a member of a professional community. It is important that the needs of all teachers from those just beginning to those in senior positions be considered. The importance of the latter is revealed in a study by Owen (1978), who found that the effectiveness of innovatory science materials in Australia depended heavily on the heads of the science department and their leadership and organizational skills.

Traditionally, the major strategies used to meet the extension and refreshment needs of teachers have included in-service programmes, workshops, regional meetings and conferences sponsored by science and science teachers' associations, tertiary institutions, ministries of education and organizations such as Unesco, the Regional Centre for Education in Science and Mathematics (RECSAM) and IPST. Such in-service activities have done much to meet the professional development needs of leading science and technology teachers in many education systems.

In most countries, the needs of the majority of science and technology teachers remain unmet. In reaching larger numbers of teachers, heavy reliance has been placed on 'low-tech' audio-visual and printed materials and short, one-off in-service days organized by central authorities. Some of these have been brought to new levels of excellence (for example, audio-visual materials produced by the International Union for Conservation of Nature and Natural Resources). However, it must be said that short courses isolated from sustained support at school and system levels are unlikely to lead to significant changes in practice. Somewhat longer modules and mini-courses have been developed to up-date teachers' knowledge in many areas. For example, the Student Assessment Project package developed at Macquarie University, Sydney, seeks to up-date teachers' understanding of assessment using a combination of tape/slide, resource material and microcomputer programmes. When used as part of a school-focused professional development programme, such materials can lead to significant changes in school policy and classroom practice.

In up-dating the professional knowledge and competencies of the mass of teachers isolated by geography or family circumstances, distance-education methods hold considerable promise. The success of the Open University in the United Kingdom has led a number of countries to experiment with the use of learning packages (study text, reader, practical work, audio- or video-casette, computer-assisted learning (CAL) packages for microcomputers and teleconferencing) and national radio and television networks to reach their teachers. In 1984, India launched a massive open-education television programme throughout the country with the establishment of the Indira Gandhi University. In Egypt, educational programmes are being televised daily to teachers enrolled in the University of Alexandria distance-education programme, together with self-training activities and regional study centres. The University of West Indies Distance Teaching Experiment illustrates how new information technologies may be used in the future to establish in-service science and technology networks. The system links six widely separated island university campuses and extra-mural centres using the International Telecommunications Satellite Organization (INTELSAT) satellite, microwave, tropospheric scatter and ultra high frequency (UHF). Slow-scan television is used to transmit and receive images and telewriters are used instead of the traditional blackboard.

All our attention ought not to be on high-tech to the neglect of the human and environmental side of the professional developmental equation. New technologies such as microcomputers certainly do have the potential for liberating teachers from obsolete practices, but they can also enslave. Science and technology teachers and in-service educators can get 'hooked' on the machine without developing any keener insight into ways of promoting their pupils' understanding of science. As educators, we must be socially responsible, remembering that it is the educational advantages of new methods rather than their technical sophistication that is important.

Attempts to coerce teachers into accepting innovations which conflict with their basic educational values are doomed to fail. When Power and Tisher (1979) studied the implementation of the Australian Science Education Project (ASEP), they found evidence of significant value conflict among over half of the experienced science teachers asked to use the materials. In many cases, teachers resisted by adopting a passive approach to the role of teacher, leading to poor achievement and attitudes among students. A conventional in-service programme did not help. A parallel group of resistant teachers involved in a collaborative action research programme did make major adjustments to their approach. Effective in-service programmes do take the principles of adult learning seriously. They respect the professionalism of teachers; they make clear the theory and rationale underlying innovations, include practical demonstrations and provide opportunities for practice and feedback. Moreover, they confront the possibility of conscientious objection and provide support in resolving problems of implementation. The professional development of teachers and the effectiveness of the implementation of science and technology programmes is also enhanced by school-focused professional and curriculum development programmes (Power, 1983).

Given their training and experience, many existing science and technology teachers do not share the conception of science or the view of teaching implied by programmes such as the Thai Community Secondary School Project, the new Malaysian Living Skills course or the Papua New Guinean School Community Extension Project. Moreover, in seeking to develop knowledge and skills for possible future vocations, several programmes (for example, *barangay* high schools in the Philippines and vocational high schools in China) involve the school directly in the production process, in making technical and ethical decisions about alternative technologies, and in implementing new ideas and methods to solve human and environmental problems. Meeting the professional developmental needs of teachers involved in such projects necessitates co-operation and co-ordinated efforts involving all the human services in a community (Case and Matthes, 1985).

Science and technology teachers, particularly qualified and committed teachers, invest significantly in terms of their own time and effort in their professional development. However, the evidence suggests that those teachers who need to spend most time preparing and expanding their knowledge and skill base are least likely to do so, and that there are enormous variations in the time science teachers are prepared to devote to their professional development. In some countries, such as Canada for example, participation in professional development activities is formally recognized and rewarded by teacher registration boards and by employing authorities, but in others like Australia, sadly, it is not. Professional development ought to be seen as a shared responsibility involving the individual teacher, the employer and professional bodies.

## Conclusion

The Unesco International Congress on Science and Technology Education and National Development in 1981 concluded that, in view of the needs of society and the rapid developments in science and technology, the demand for science teachers is increasing and that they are expected to be:

> (a) proficient in one or more science subjects or in integrated science, and able to interrelate science and technology; (b) able to interpret and teach in a technological and social context; (c) knowledgeable about the social and economic implications of science and technology; (d) competent in the skills needed for a variety of classroom teaching/learning modes, including evaluation; and (e) flexible in personal style and able to cope with change [Unesco, 1983, p. 137].

It seems clear that a great deal needs to be done to ensure that those graduating from pre-service programmes and being offered employment meet these expectations. It is also apparent that there are a great many existing teachers who have not been trained to teach science, technology and society programmes of the type being developed and that, without adequate in-service and advisory support, there will undoubtedly be a good deal of confusion, conflict and poor teaching. Highest priority, therefore, should be given to the professional development of existing teachers. There is no simple administrative device (inspection, national testing or whatever) which will guarantee an improvement in the quality of teaching or ensure that teachers and pupils become more flexible and responsive to the possibilities created by new ideas and methods. In schools, there is no path to excellence other than the extension and refinement of the professional judgement, knowledge base and social sensitivity of its teaching service.

The context within which teaching occurs is also vitally important for it may encourage or inhibit the opportunity and the will to change, and to continue to learn, of both students and teachers. Professional leadership, and school and systems policies designed to encourage teachers to keep up-to-date and to strive for excellence are needed. It is also suggested that the resources and effort needed to improve the provision of science and technology teachers will not be forthcoming if strategies are not developed to improve community and political understanding of, and commitment to, science, technology and education. The successful tackling of all these tasks lies beyond the expertise of most countries. While each country must seek its own solution in the light of available resources, there is much to be gained by supporting co-operative efforts of professional, regional and international organizations.

# References

AMEH, C.O.; GUNSTONE, R. 1986. Misconceptions in Chemistry amongst Nigerian Science Teachers. In: J. Devenport and D. Mulcahy (eds.), *Chemistry and its Communication: Towards 2000*, pp. 222–9. Canberra, Royal Australian Chemical Institute.

ASTA (AUSTRALIAN SCIENCE TEACHERS' ASSOCIATION). 1984. *The Place of Science in the K–12 Curriculum of Australian Schools.* Canberra, ASTA.

BROPHY, J.; GOOD, T. 1986. Teacher Behavior and Student Achievement. In: M.C. Wittrock (ed.), *Handbook of Research on Teaching*, 3rd ed., pp. 328–75. New York, Macmillan.

CASE, C.; MATTHES, W. (eds.). 1985. *Colleges of Education: Perspectives on their Future.* Berkeley, Calif., McCutchan.

DUNKIN, M.; BARNES, J. 1986. Research on Teaching in Higher Education. In: M.C. Wittrock (ed.), *Handbook of Research on Teaching*, 3rd ed., pp. 754–77. New York, Macmillan.

EGBERT, R.L. 1985. The Practice of Preservice Teacher Education. *Journal of Teacher Education*, Vol. 36, No. 1, pp. 16–21.

HAWLEY, W.D. 1986. Toward a Comprehensive Strategy for Addressing the Teacher Shortage, *Phi Delta Kappan*, Vol. 67, No. 10, pp. 712–18.

INSTITUTE OF MANPOWER STUDIES. 1984. *Competence and Competition: Training and Education in the Federal Republic of Germany, the United States and Japan.* London, National Economic Development Office/Manpower Services Commission.

JACOBSON, W.J. (ed.). 1986. *Environmental Education: Module for Pre-service Training of Science Teachers and Supervisors for Secondary Schools.* Paris, Unesco. (Unesco-UNEP International Environmental Education Programme, Environmental Education Series, 7.) (Unesco doc. ED–86/WS/55.)

LANIER, J.; LITTLE, J. 1986. Research on Teacher Education. In: M.C. Wittrock (ed.), *Handbook of Research on Teaching*, 3rd ed., pp. 527–69. New York, Macmillan.

OSBORNE, R.; FREYBERG, P. 1985. *Learning in Science: The Implications of Children's Science*, Auckland, Heinemann.

OWEN, J. 1978. *The Impact of the Australian Science Education Project on Schools.* Canberra, Curriculum Development Centre.

OWEN J.; JOHNSON, N.; WELSH, R. 1985. *Primary Concerns: A Project on Mathematics and Science in Primary Teacher Education.* Melbourne, Melbourne College of Advanced Education.

POWER, C. 1983. Teacher Development at the School Level. *South Pacific Journal of Teacher Education*, Vol. 11, No. 2, pp. 1–11.

——. 1984. Tinker, Tailor, Soldier, Spy. Implications of Science Education Research for Teachers. *Science Education*, Vol. 68, No. 2, pp. 179–93.

——. 1986. Providing High Quality Teachers and Support Staff for the

Inter-related Teaching of Science, Technology and Mathematics. *Science and Public Policy*, Vol. 13, No. 3, pp. 134–46.

POWER, C.; TISHER, R. 1979. A Self-paced Environment. In: H. Walberg (ed.), *Educational Environments and Effects*, pp. 200–17. Berkeley, Calif., McCutchan.

PROUT, A. 1985. Science, Health and Everyday Knowledge. A Case Study about the Common Cold. *European Journal of Science Education*, Vol. 7, No. 4, pp. 399–406.

ROYAL SOCIETY. 1985. *Science is for Everybody*. London, Royal Society. (Shorter version of *The Public Understanding of Science*.)

SWEITZER, G.; ANDERSON, R. 1983. A Meta-analysis of Research on Science Teacher Education Practices Associated with Inquiry Strategy. *Journal of Research in Science Teaching*, Vol. 20, No. 5, pp. 453–66.

TISHER, R.; FRYFIELD, J.; TAYLOR, S. 1979. *Beginning to Teach*. Vol. 2. Canberra, AGPS (ERDC Report, No. 20.)

UNESCO. 1983. *Science and Technology Education and National Development*. Paris, Unesco.

Inter-related Teaching of Science, Technology and Mathematics, *Science and Public Policy*, Vol. 13, No. 3, pp. 124–48.

Powers, C.; Tisher, R. 1979. A Self-paced Environment. In: H. Walberg (ed.), *Educational Environments and Effects*, pp. 200–17, Berkeley, Calif., McCutchan.

Prout, A. 1985. Science, Health and Everyday Knowledge. A Case Study about the Common Cold. *European Journal of Science Education*, Vol. 7, No. 4, pp. 399–406.

Royal Society. 1985. *Science is for Everybody.* London, Royal Society. (Shorter version of *The Public Understanding of Science*.)

Sweitzer, G.; Anderson, R. 1983. A Meta-analysis of Research on Science Teacher Education Practices Associated with Inquiry Strategy. *Journal of Research in Science Teaching*, Vol. 20, No. 5, pp. 453–66.

Tisher, R.; Fyfield, J.; Taylor, S. 1979. *Beginning to Teach*. Vol. 2. Canberra, AGPS. (ERDC Report No. 20.)

Unesco. 1983. *Science and Technology Education and National Development*. Paris, Unesco.

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